Volume 14 AUGUST 1930 Number 8

BULLETIN
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American Association *of* Petroleum Geologists

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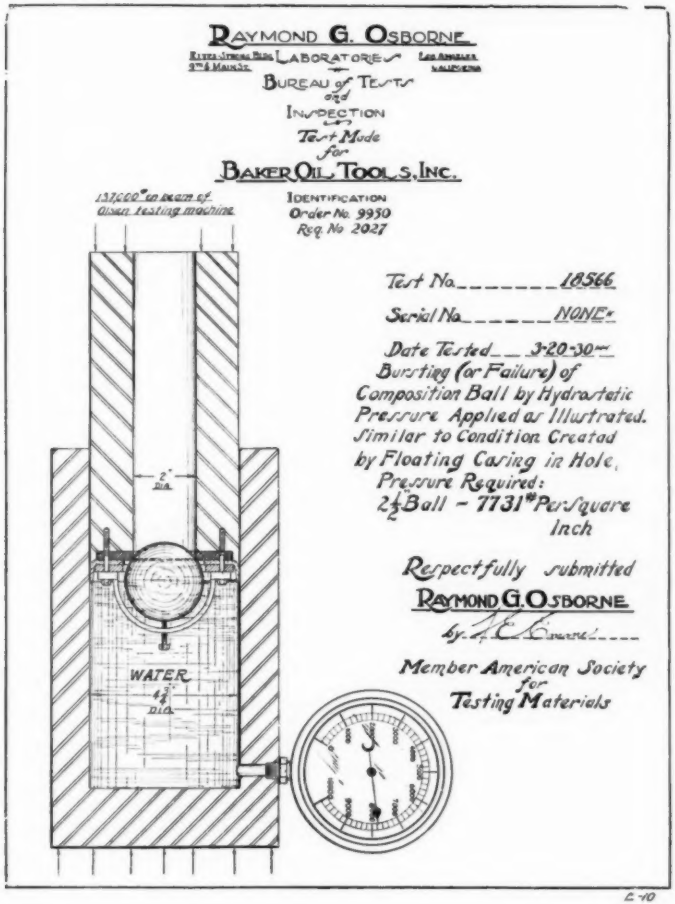

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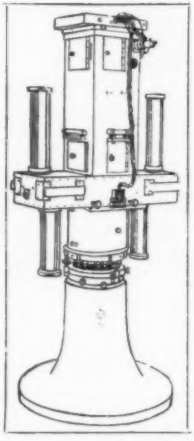

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BULLETIN

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AUGUST 1930

TRANSVERSE SECTION OF PERMIAN BASIN, WEST TEXAS AND SOUTHEAST NEW MEXICO[1]

LON D. CARTWRIGHT, JR.[2]
San Angelo, Texas

ABSTRACT

The Permian basin is divided into structural units each of which is characterized by a distinctive stratigraphic section. The Main Permian basin, Central basin platform, and Delaware Mountain basin are included in the transverse section presented in this paper. The strata of the Main Permian basin are divided into the Wichita-Albany, Clear Fork, and Double Mountain groups, the Double Mountain group being divided into the San Angelo, Blaine, Whitehorse-Cloudchief, and Quartermaster formations. The formations of the Main Permian basin are relatively uniform along the strike, but thicken and become more marine basinward.

The Central basin platform is a regional limestone "high" on which there are pronounced changes in the limestone section penetrated east and west across it. Two explanations of these changes are generally accepted. The first recognizes an extension of the Capitan reef system bordering the Delaware Mountain basin. Back of the reef is a lagoonal facies comprising dolomitic limestone, sandstone, and anhydrite. The second recognizes an older dolomitic limestone known as the "White lime," on the eroded surface of which there is a heterogeneous deposit of dolomitic limestone, sandstone, and anhydrite known as the "Brown lime."

The strata of the Delaware Mountain basin comprise the Bone Springs limestone, the Delaware Mountain sandstone, the Capitan formation, the Lower Castile, Upper Castile, and Rustler formations. Of especial interest are the Capitan, which is a reef phase of the upper Delaware Mountain, and the Lower Castile, which is a peculiar evaporite formation.

INTRODUCTION

The most recently published cross section of the Permian basin of West Texas and southeastern New Mexico was that of E. C. Edwards,[3]

[1]Manuscript received by the editor, March 10, 1930.

[2]Geologist, Superior Oil Company of California.

[3]E. C. Edwards, "Stratigraphic Position of the Big Lime of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 7 (July, 1927), pp. 721-28.

which accompanied a well prepared discussion of the stratigraphic problems of the basin as they were then understood. Since that time a wealth of new information has become available. Many additional wells have been drilled throughout the district, and samples of drill cuttings from them have been saved. Much has been written describing the stratigraphy of the Permian outcrop on the margins of the basin, and there have been comprehensive discussions of the subsurface stratigraphy.

In the light of this increased knowledge the early conceptions of the cross section of the basin have changed. It is the purpose of the writer to set forth a new interpretation. Plate 2 illustrates correlations across the basin, based on logs prepared chiefly from microscopic examination of cuttings. Plate 3 is an idealized section through the same wells. The discussion presented in this paper relates directly to the Permian stratigraphy along this line of section, and only indirectly to the general region.

GENERAL STRUCTURE AND STRATIGRAPHY

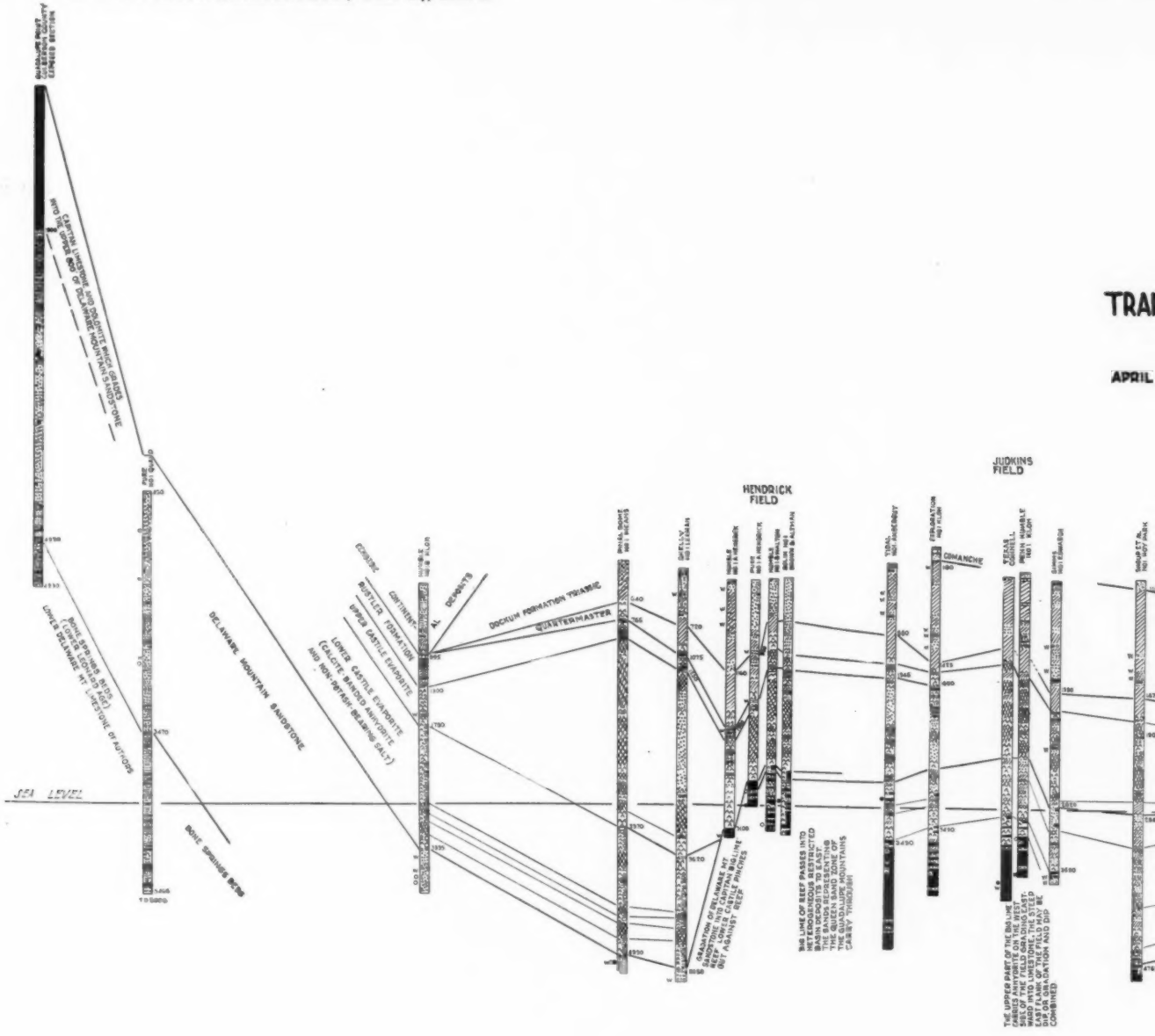
The Permian basin province is divided into several structural units as illustrated in Figure 1, each of which is characterized by a distinctive stratigraphic section. The units included in the transverse section presented in this paper are designated the Main Permian basin, the Central basin platform, and the Delaware Mountain basin. The Main Permian basin is an asymmetrical basin in which the Permian formations are relatively uniform in lithology along the strike, but thicken basinward from east to west and change from land-marginal to marine lithology in the same direction.

The Central basin platform is a broad, structural ridge with a huge dolomite reef on its western rim. Formations are relatively uniform along the strike, but across the strike there are pronounced gradations of the lower formations. Solution of salt and consequent slumping have disturbed the upper formations above the reef.

Inasmuch as the Delaware Mountain basin was an area of regional subsidence during the deposition of all its known formations, it received a great thickness of sediments. In the basin the lower formations are remarkably uniform in lithology, but the younger formations show variations both in lithology and thickness.

STRATIGRAPHY OF MAIN PERMIAN BASIN

On the east side of the Permian basin a broad belt of Permian formations is exposed from San Angelo at the south into western Kansas at the north. These beds are divided into the Wichita-Albany, Clear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APRIL
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DELAWARE MOUNTAIN SANDSTONE
BONE SPRINGS SITE
SEA LEVEL
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THE LINE OF BEEF PASSES INTO HETEROGENEOUS RESTRICTED BASIN DEPOSITS TO EAST
THE BASAL SEDIMENTS OF THE QUEEN SAND ZONE OF THE GUADALUPE MOUNTAINS GRADE THROUGH
EROSION OF DELAWARE MT. MOUNTAIN BEHIND THE CAPITAN BIOLITHE BARRIER REEF, A LONG STEEP BIOLITHE DIP AGAINST DEEP WATER
THE UPPER PART OF THE BIG LIME FABRIC ANHYDRITE ON THE WEST SIDE OF THE FIELD GRADES EAST WARD INTO LIMESTONE, THE STEEP EAST FLANK OF THE FIELD MAY BE ALL ANHYDRITE AND DIP COMBINED

TRANSVERSE CROSS SECTION WEST TEXAS PERMIAN BASIN

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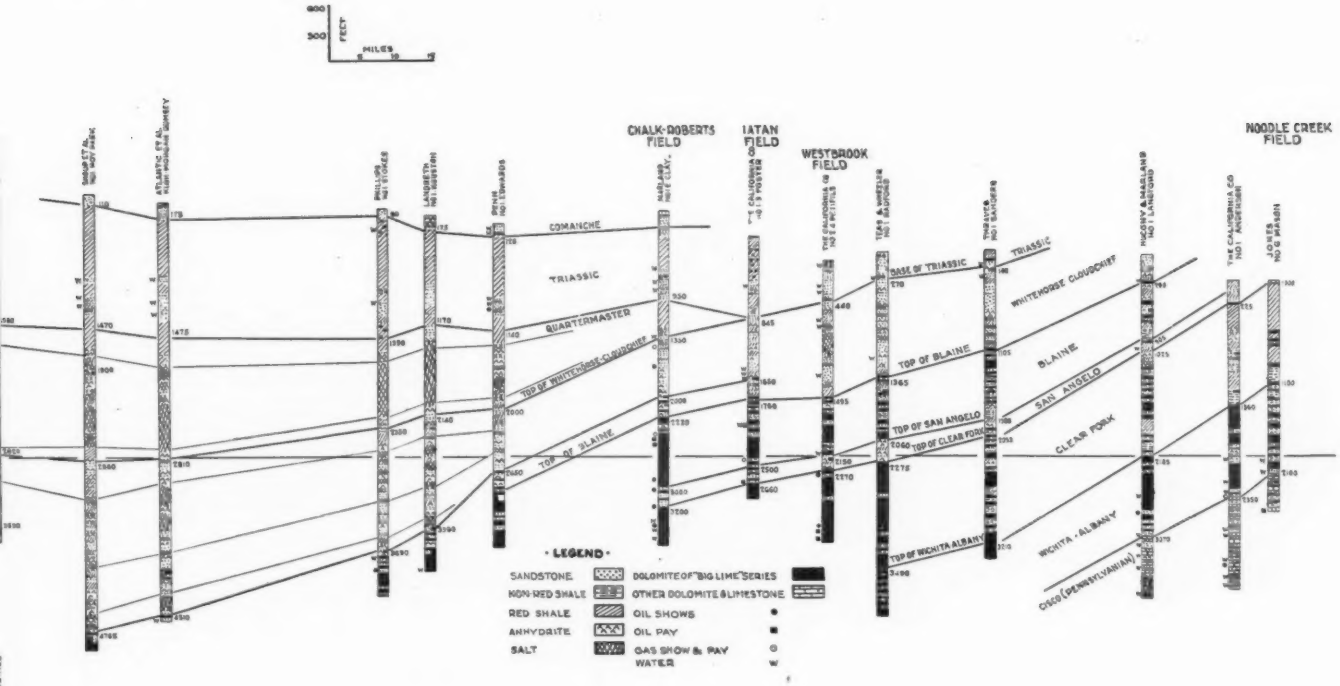
APRIL 1930

LON D. CARTWRIGHT JR



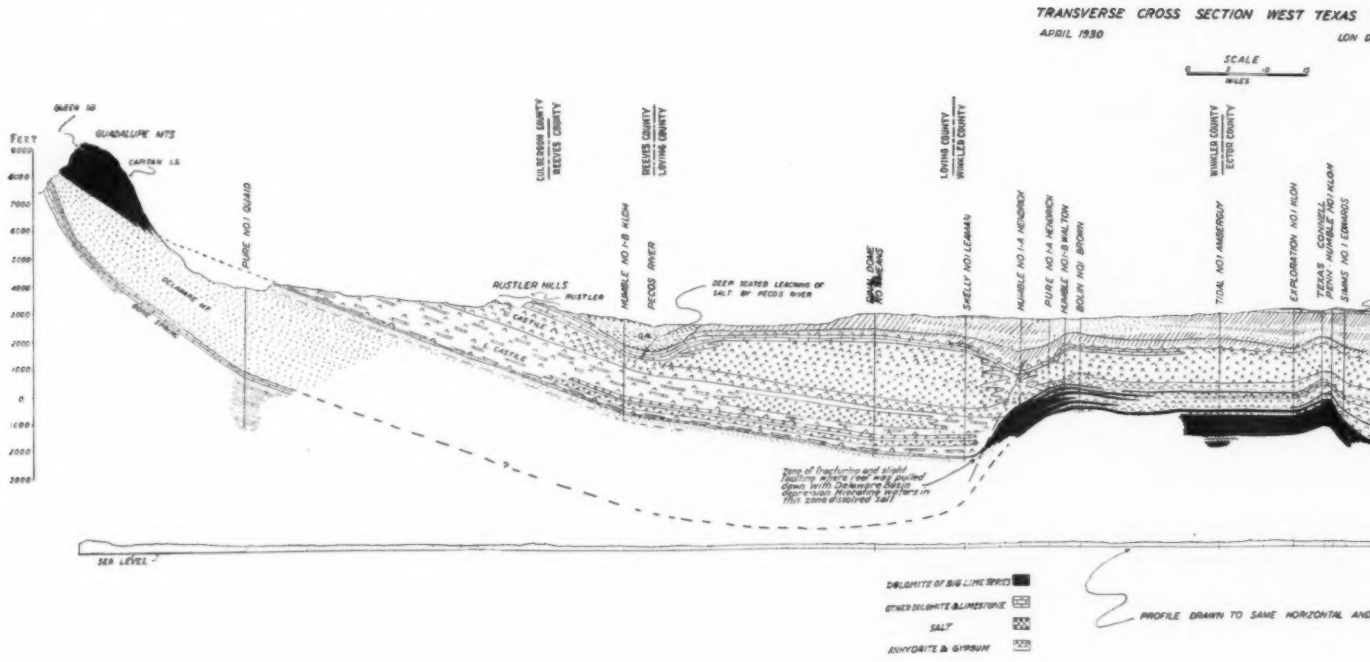
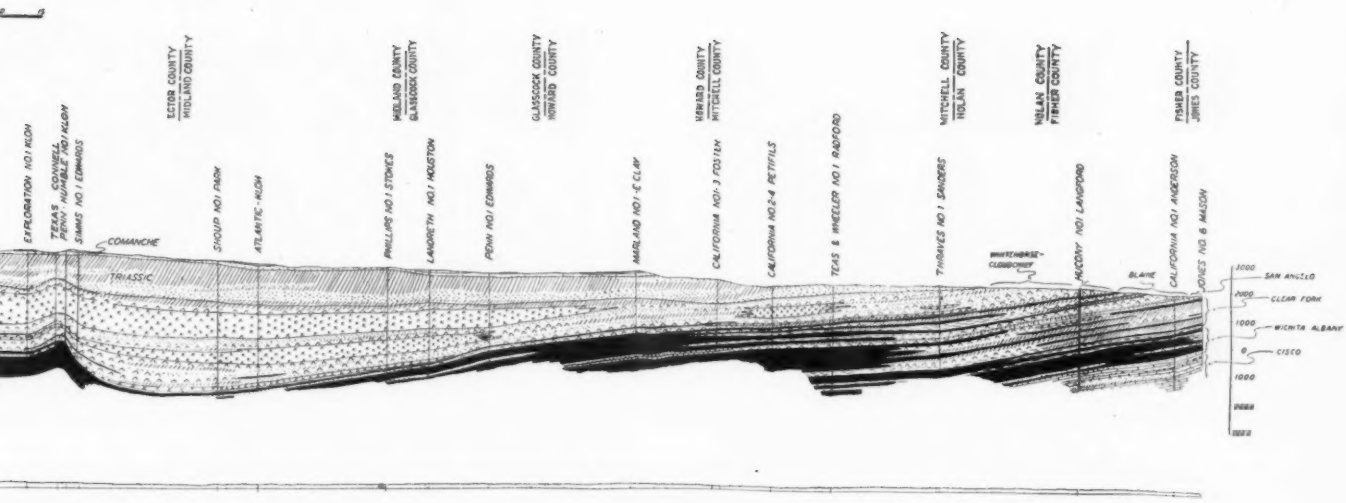

TRANSVERSE CROSS SECTION WEST TEXAS
APRIL 1930
SCALE
QUEEN HD
GUADALUPE MTS
CAPITAN U.S.
FEET
PURE NO 1 QUAD
CULBERSON COUNTY
REEVES COUNTY
REEVES COUNTY
LOVING COUNTY
HUMBLE NO 1-B KLOH
PECOS RIVER
RUSTLER HILLS
RUSTLER
CASTILE
DEEP SEATED LEACHING OF SALT BY PECOS RIVER
SPAN DOME
SKELLY NO 1 LEAMAN
LOVING COUNTY
WINKLER COUNTY
HUMBLE NO 1-A HENDRICK
PURE NO 1-A HENDRICK
HUMBLE NO 1-B WALTON
BOLIN NO 1 BROWN
WINKLER COUNTY
ECTOR COUNTY
TIDAL NO 1 AMBEROUY
EXPLORATION NO 1 KLOH
TEXAS COMPANY
PECOS VALLEY NO 1 KLOH
SIMMS NO 1 EDWARDS
Zone of fracturing and slight faulting where roof has pulled down with Delaware Basin depression. Receding waters in this zone dissolved salt
SEA LEVEL
DOLOMITE OF BIG LIME SERIES
OTHER DOLOMITE & LIMESTONE
SALT
ANHYDRITE & GYPSUM
PROFILE DRAWN TO SAME HORIZONTAL AND

PLATE 3

WEST TEXAS PERMIAN BASIN

LON D. CARTWRIGHT JR.



E HORIZONTAL AND VERTICAL SCALE

RED SHALE
NON-RED SHALE
SANDSTONE

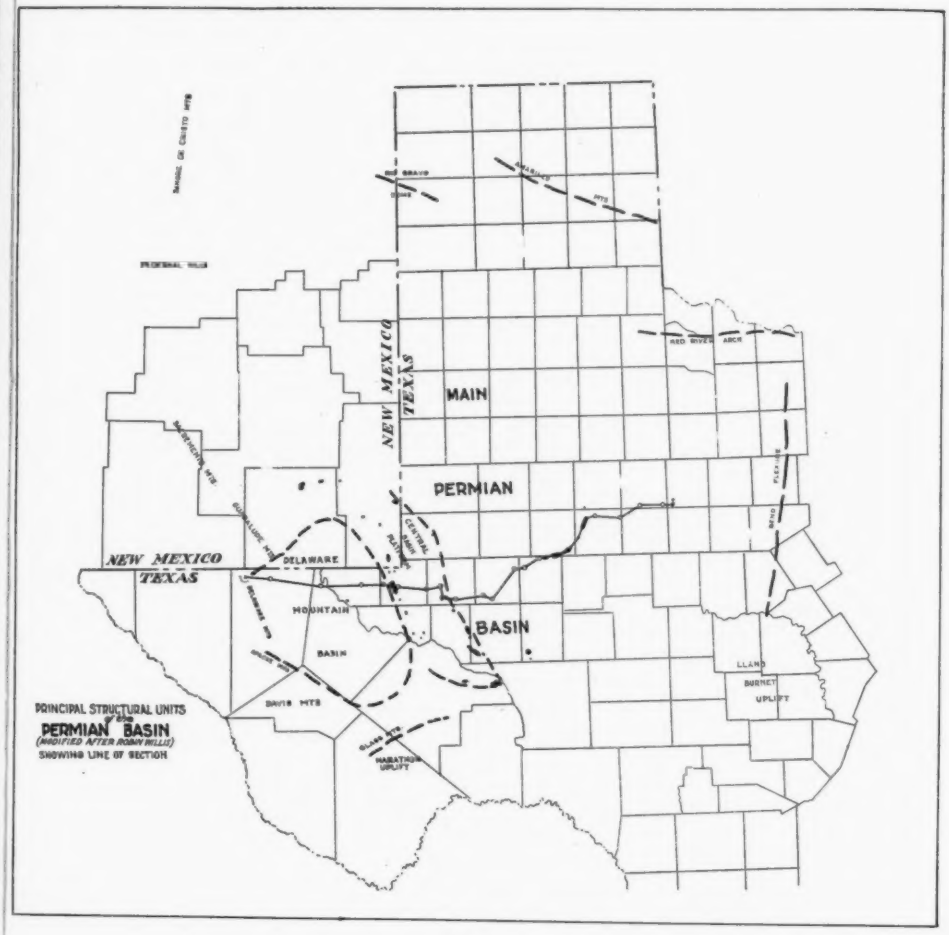

NEW MEXICO
TEXAS
MAIN
PERMIAN
BASIN
DELAWARE
MOUNTAIN
BASIN
DAVIS MTS
RED RIVER ARCH
LLANO
BURNET
UPLIFT
MARATHON UPLIFT
PRINCIPAL STRUCTURAL UNITS
OF THE
PERMIAN BASIN
(MODIFIED AFTER ROBIN WILLIS)
SHOWING LINE OF SECTION

FIG. 1

Fork, and Double Mountain groups. The stratigraphic column and areal map recently published by Lloyd and Thompson[1] were used as guides in correlating the subsurface formations of the east side of the Main Permian basin.

The Wichita-Albany group is a fossiliferous marine limestone and shale series approximately 900 feet thick in the southern part of its outcrop. It continues westward in the subsurface as limestone and shale, limestone being predominant. In the upper part of the group the limestones are dolomitic and in the lower part non-dolomitic. Basinward from the outcrop the contact between dolomitic and non-dolomitic limestone is progressively lower in the section.

The Clear Fork group consists chiefly of Red-beds at the outcrop, but assumes more and more marine characteristics basinward, and passes through a phase in which it is represented by Red-beds, anhydrite, and dolomitic limestone, into a phase in which it is nearly all dolomitic limestone. This striking transition is illustrated in the idealized cross section (Plate 3).

The Double Mountain group, which is the most interesting group on the east side of the basin, consists of several distinct formations easily traceable on the surface. The lowest formation of this group is the San Angelo, which rests unconformably on the Clear Fork. It ranges from 175 to 225 feet in thickness and consists of pebbly sand and red shale at the east end of the section, passing through a sand, anhydrite, and red shale facies in Mitchell County into a fine sand and dolomitic limestone facies in eastern Howard County.

Overlying the San Angelo is the Blaine formation, which at the outcrop at the east end of this section consists of 375 feet of gypsum, red and blue shale, and a few dolomite beds. In the subsurface the Blaine thickens basinward and becomes more and more calcareous as far as eastern Howard County, where it is 780 feet thick and is predominantly dolomitic limestone.

The Blaine is overlain at the outcrop by the Whitehorse sandstone and Cloudchief gypsum, which were grouped by Lloyd and Thompson,[2] because of the difficulty of dividing them in the southern part of the area in which they crop out. The Whitehorse-Cloudchief is a formation ranging from 700 to 900 feet in thickness, consisting predominantly of

[1] A. M. Lloyd and W. C. Thompson, "Correlation of the Permian Outcrops on the Eastern Side of the West Texas Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 945-56.

[2] *Op. cit.*

red sandstone and shale in the lower part and gypsum in the upper. It is overlain unconformably by the Triassic at the east end of this section.

Westward in the subsurface the Whitehorse-Cloudchief contains several salt beds in Mitchell County, which pinch out in the Chalk-Roberts field in southeast Howard County, but which occur west of that field. In Midland County, which is the lowest part of the Main Permian basin, the Whitehorse-Cloudchief increases to approximately 2,000 feet of red sand, red shale, anhydrite, salt, and dolomite. Westward from the Iatan field in Mitchell County, there is a dolomite bed low in the formation which constitutes the top of the "Big lime" in a large part of the Main Permian basin.

Although the sand of the Whitehorse-Cloudchief, which is composed of fine and very fine, subrounded, well sorted quartz grains, is red for the most part, it is gray and brown in the Chalk-Roberts field, where hydrocarbons and sulphur gas probably have reduced the ferric oxide stain to the easily soluble ferrous oxide. Mixed in some of the beds of fine sand are coarse, rounded, frosted quartz grains, which are especially noticeable in some of the shallow pay sands of the Chalk-Roberts field. The lithology of these phases of the Whitehorse-Cloudchief is identical with the lithology of the Yates sand as described by John Adams and the writer.[1] The top of the Whitehorse-Cloudchief extends westward into the top of the Queen sand zone, thus confirming a paleontologic correlation made by Beede[2] in 1910.

The Whitehorse-Cloudchief is normally overlain at the outcrop by the Quartermaster red sands and shales, but in the line of this section the Quartermaster is overlapped by Triassic. It comes in westward in the subsurface, however, as indicated on Plate 2.

Between the definite Quartermaster and definite Whitehorse-Cloudchief in the Main Permian basin, a thick salt wedge constitutes the "main salt" of the basin and is correlated with the Upper Castile of the Delaware Mountain basin. Although it is difficult to say what is the outcrop equivalent of this salt member on the east side of the basin, the writer suggests that it is either an intercalated bed not represented in the outcrop, or equivalent to a part of the lower Quartermaster.

The Triassic Dockum formation, composed of red and gray clays, coarse sands, and gravels of continental origin, occupies a considerable

[1]Quoted in G. C. Gester and H. J. Hawley's "Yates Field, Pecos County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), pp. 480-99.

[2]J. W. Beede, "Correlations of the Guadalupian and Kansas Sections," *Amer. Jour. Sci.*, Vol. 30 (1910), pp. 131-40.

interval in the stratigraphic section, as reference to Plate 3 shows. It has been well described by Adams[1] and is of little direct economic importance. In the southern part of the Main Permian basin it is overlain by Comanche sands, clays, and limestones.

STRATIGRAPHY OF CENTRAL BASIN PLATFORM

The stratigraphy of the limestone formations of the Central basin platform is probably the most disputed subject to-day among geologists studying the Permian basin, because of the rapid and important changes in section, as recorded in drill cuttings from relatively near-by wells. There are two main explanations for these changes. One attributes the changes principally to gradation in character of sediments of equivalent age. The other attributes the changes principally to overlap relations of a heterogeneous deposit on the eroded surface of an older homogeneous limestone formation.

The writer's conception of the Central basin platform is illustrated in Plate 3. The limestone formations of this structural unit are distinctive. It is the writer's opinion that the dolomitic limestone section of the west edge of the platform is a reef system consisting of the reef proper, probably penetrated in Humble's Hendrick No. 1-A, and a back-reef or lagoonal facies of detrital lime-mud beds, algal pisolite, sandstone, and, farther east, anhydrite. The Hendrick field, located close to the reef, is principally in the lagoonal facies, and its oil seems to be obtained principally from pisolite.[2]

This reef system is distinguished by its position on a high rim bordering the Delaware Mountain basin, and by pronounced lateral gradations from an entirely dolomitic limestone section, through a facies of dolomitic limestone and sandstone with progressively more anhydrite, into a section predominantly anhydrite with some sand and some dolomitic limestone. This gradation takes place in a direction normal to the rim of the Delaware Mountain basin and away from it, and is complete within a distance ranging from 8 to 15 miles.

The reef system is definitely traced in well logs through an arc from the Hendrick field to Carlsbad, New Mexico, where the Capitan reef

[1]John E. Adams, "Triassic of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 1045-56.

[2]Through the courtesy of the California Company, the Shell Petroleum Corporation, the Atlantic Oil Producing Company, and the Southern Crude Oil Purchasing Company, in August, 1928, the writer was enabled to examine many sets of cores taken from the producing formations and found that almost invariably the oil was coming from a pisolite. Specimens of this pisolite sent to David White were pronounced to be the alga *Gervinella*.

system dips below younger beds. Moreover, the peculiarly distinctive lithology of many of the Hendrick field cores as shown in polished surfaces is practically identical with the lithology of outcrop specimens from the Capitan reef systems of the Guadalupe Mountains and the Apache Mountains; hence, the reef in the subsurface is correlated with the Capitan reef system. The relations of the Capitan, Delaware Mountain, Carlsbad, Queen, and Seven Rivers formations and members, as studied in the field, have been ably described[1] by Lloyd, Crandall, and Blanchard and Davis, and it is chiefly due to these data obtained from outcrops that a proper interpretation of the subsurface relations can be made.

The correlation of the "Big lime" section of the eastern part of the Central basin platform with the limestone series in the Main Permian basin farther east is still problematical. It may be as shown in Plate 2, or there may be gradations into anhydrite.

The alternative interpretation of the Central basin platform stratigraphy is illustrated in Figure 2. The Central basin platform is an eroded arch in the "White lime," a formation composed chiefly of white and gray dolomitic limestone and either equivalent to, or older than, the Delaware Mountain. The Hendrick field lies on a fold on the west rim of the platform. The platform was overlapped from the east by a heterogeneous deposit called the "Brown lime." This consists of a little brown dolomitic limestone, anhydrite, Red-beds, and sand and some salt members east of the platform, which, passing westward over the platform, thins and grades into brown dolomitic limestone and sandstone with a small amount of anhydrite on the east flank of the Hendrick fold, and into brown dolomitic limestone on its crest.

This second interpretation was formerly accepted generally, but the results of surface stratigraphic work in the Guadalupe Mountains and the evidence of many wells drilled during the past two years in Winkler County, Texas, and Lea and Eddy counties, New Mexico, have led to the widespread acceptance of the form of the interpretation first described.

[1] E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 645-58.

K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 927-44.

W. Grant Blanchard, Jr., and Morgan J. Davis, "Permian Stratigraphy and Structure of Parts of Southeastern New Mexico and Southwestern Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 957-95.

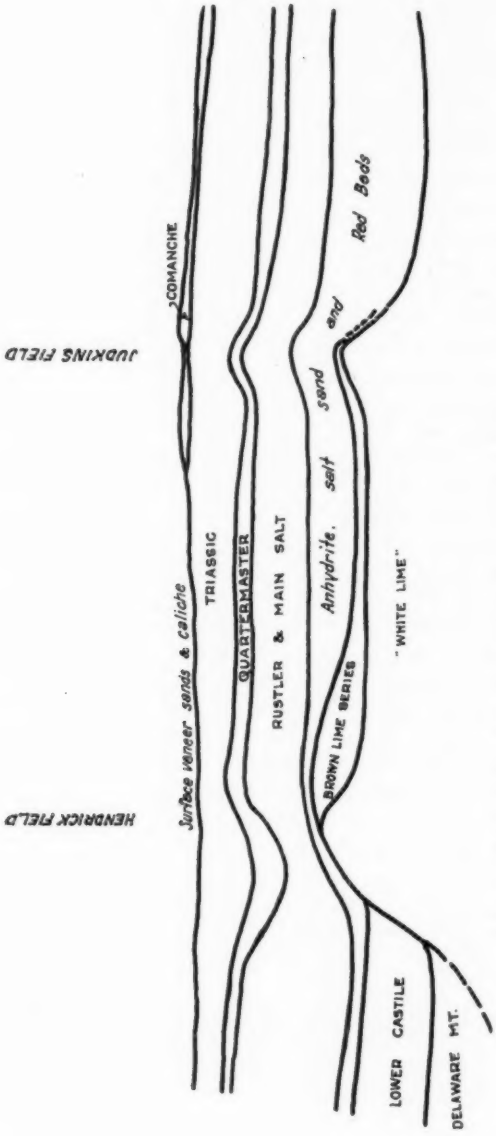


FIG. 2.—Stratigraphy of Central basin platform according to alternative interpretation.

STRATIGRAPHY OF DELAWARE MOUNTAIN BASIN

The Permian formations of the Delaware Mountain basin are well exposed at the west side of the basin and consist of the Bone Springs limestone, Delaware Mountain sandstone, Capitan, Lower Castile, Upper Castile, and Rustler.

At the west end of this cross section, the lowest rocks exposed are 600 feet of black limestone and shale of the lower member of the Bone Springs formation. The Bone Springs limestone is the name given by Blanchard and Davis[1] to the lower part of the Delaware Mountain formation as originally described by Richardson[2] and has also been described by other writers as the Bone Canyon formation and the lower Delaware Mountain formation. Eastward along this cross section, 2,000 feet of this formation and probably older formations are penetrated in The Pure Oil Company's Quaid No. 1. The beds penetrated consist predominantly of black shale, but also contain a little limestone and two heavy sand beds.

In the idealized cross section (Plate 3), the top of the Bone Springs is extended eastward and raised in an arch to the Central basin platform. This correlation is assumed because the Bone Springs is correlated with the Leonard by the King brothers,[3] on paleontologic evidence, and the Leonard and possibly lower Word are correlated with the San Angelo and Blaine by Beede,[4] on the evidence of ammonites.

The Delaware Mountain sandstone, which rests on the Bone Springs, consists of 3,500 feet of gray and buff sandstone with a very little limestone and dark shale in the line of this section. The top of the formation throughout the Delaware Mountain basin is a distinctive member of dark shaly limestone, grading laterally into black shale, the average thickness being 50 feet.

On the southeast flank of the Guadalupe Mountains, the upper part of the Delaware Mountain sandstone grades abruptly into a limestone reef facies known as the Capitan formation. The details of this gradation as exposed in the walls of McKittrick Canyon are illustrated in Figure 3, cross sections made by Robin Willis, Alvin P. Loskamp, and

[1]W. Grant Blanchard, Jr., and Morgan J. Davis, *op. cit.*

[2]G. B. Richardson, *op. cit.*

[3]P. B. King and R. E. King, "Stratigraphy of Outcropping Carboniferous and Permian Rocks of Trans-Pecos Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 907-26.

[4]J. W. Beede and D. D. Christner, "The San Angelo Formation and Geology of Foard County," *Univ. Texas Bull. 2607* (1926).

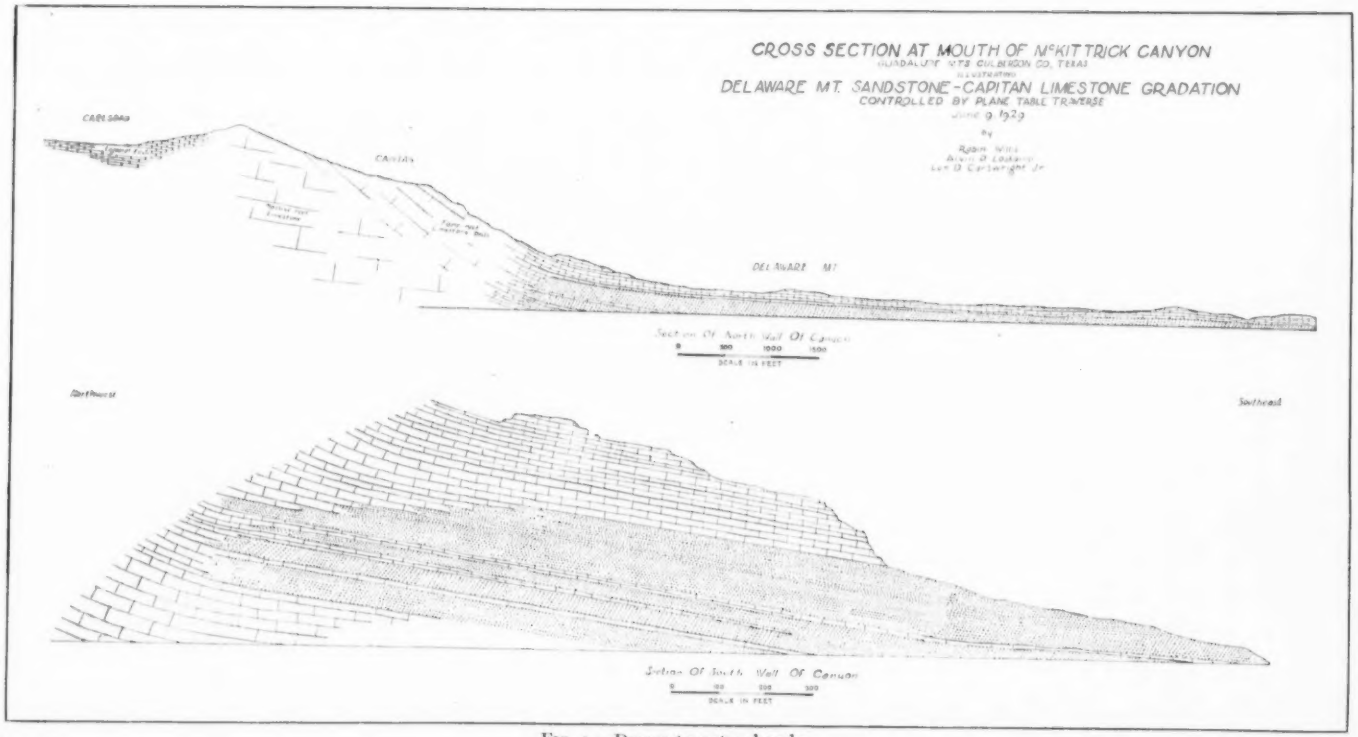


FIG. 3.—Drawn to natural scale.

the writer. Approximately 1,000 feet of the Delaware Mountain sandstone grades into limestone, according to Blanchard and Davis,[1] who describe this feature, as do Crandall[2] and Lloyd.[3]

The Capitan reef system consists of a huge core of massive limestone, poorly stratified fore-reef beds of limestone with an initial dip of as much as 25°, and lagoonal beds of thin-bedded limestone. The thickness at Guadalupe Point is 1,800 feet, and the limestone is both dolomitic and non-dolomitic. Profound lateral changes take place in the section behind the reef, the result being that the interval represented by thin-bedded dolomitic limestones immediately adjacent to the reef is represented by interbedded sandstone, dolomitic limestone, and gypsum back from the reef, and the proportion of dolomitic limestone decreases away from the reef and the proportion of gypsum increases.

The Delaware Mountain formation is overlain conformably by the Castile gypsum, originally described by Richardson[4] and named for the Castile Springs in northern Culberson County. Subsurface work from sample logs shows that the Castile consists of two very different evaporite formations.

The Lower Castile consists of 1,500 feet of interbedded pure gypsum, calcite-laminated gypsum, smaller quantities of laminated gypsiferous, petroliferous limestone, a very little gray shale; and, in the eastern part of the Delaware Mountain basin, white potash-poor salt. In the drill cuttings the gypsum is represented chiefly by anhydrite. The upper part of the Delaware Mountain formation is laminated, and the contact between it and the Lower Castile is a gradation from laminated limestone to calcite-banded, laminated gypsum. The salt beds of the eastern part of the basin are remarkably uniform throughout many miles, especially the two lower beds, and are not wedges thickening the part of the section in which they occur, for where they are absent there is an equivalent thickness of anhydrite.

The Lower Castile is restricted in areal extent to the Delaware Mountain basin, where it is of rather uniform distribution. This fact, considered with its character as an evaporite, indicates that it had its origin in an enclosed basin, the water in which was replenished from

[1]W. Grant Blanchard, Jr., and Morgan J. Davis, *op. cit.*

[2]K. H. Crandall, *op. cit.*

[3]E. Russell Lloyd, *op. cit.*

[4]G. B. Richardson, "Report of a Reconnaissance in Trans-Pecos Texas North of the Texas-Pacific Railway," *Univ. Texas Mineral Survey Bull. 1904.*

outside sources. The calcite laminae, which are ordinarily dark with petroliferous matter and organic residue, are interpreted by the writer to indicate that immediately following recurrent replenishing of the restricted sea with normal marine water, the calcium carbonate was precipitated because of super-saturation, and the organisms which were washed in were killed and their remains deposited with the calcite.

Udden[1] has contributed a well illustrated description of a series of cores of this formation taken in the David Flood core test drilled in eastern Culberson County. He[2] asserts "there is no doubt in my mind that these are annual cycles," referring to the time periods indicated by the laminae in the anhydrite. Since he says there are 300,000 laminae in the 1,600 feet of the formation, the time required for deposition of this remarkable formation may have been approximately 300,000 years, "somewhat commensurate with the estimated duration of some of our glacial periods in the Quaternary."

The salt beds of the Lower Castile are limited to the eastern part of the Delaware Mountain basin, and the total thickness there is approximately the same as farther west where the salt is absent. Thus, while salt was being deposited in the eastern part of the basin, anhydrite was being deposited in the western part. It is inferred from this fact that replenishing normal marine waters entered the basin from the west, probably over a barrier bar; that they moved eastward, becoming increasingly more saline, because of evaporation, as they moved; that evaporites of less solubility were precipitated first and evaporites of more solubility, for example, salt, were precipitated later farther from the source.

The Upper Castile formation, a massive gypsum and anhydrite unit approximately 800 feet thick at the outcrop, thickens within a short distance eastward in the subsurface and contains the massive potash-bearing "main salt" in the eastern part of the Delaware Mountain basin and farther east to Howard County. Dolomitic limestone, red shale, and sandstone are present in some places in the Upper Castile. Inasmuch as the Upper Castile differs from the Lower Castile in composition, primary structure, areal extent, sedimentary relations, and significance, it is here classed as a separate formation, although it is practically impossible to map the contact between the two formations on the surface because very poor exposures occur in the gypsum plain.

[1] J. A. Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. Amer.*, Vol. 35 (June, 1924), pp. 347-54.

[2] *Idem*, "A Neglected Field in Stratigraphy," *Univ. Texas Bull. 2801* (1928), p. 65.

The Rustler formation at the outcrop consists of approximately 200 feet of gray dolomitic limestone overlying 20 feet of yellow sandstone, locally conglomeratic, and 3 feet of red and gray clay which rests on the Upper Castile. The contact between this red and gray clay and the Upper Castile is probably unconformable. Eastward in the subsurface the Rustler extends beneath the Quartermaster Red-beds and pinches out possibly as far east as Midland County.

CONCLUSION

Throughout this paper the "top of the lime" correlations have received little mention. They are generally more or less arbitrary datum points, of value in limited areas only. As more information on the subsurface stratigraphy of a region becomes available, it becomes possible to divide the entire section into recognizable formations, and only after this has been done can the regional relationships and geologic history of a district be determined. With more and more information becoming available on Permian basin stratigraphy, it is increasingly important that correlations be made with formational units, and it is as an approach to this problem that this paper is offered.

DEEP SAND DEVELOPMENT IN COTTON VALLEY FIELD, WEBSTER PARISH, LOUISIANA[1]

J. S. ROSS[2]
Shreveport, Louisiana

ABSTRACT

The development of the deep horizons in the Cotton Valley field began in 1926 with the discovery of gas in the anhydrite zone of the Glen Rose formation. The productive sands are found below the anhydrite at depths ranging from 4,500 to 4,700 feet. They are lenticular in structure and productive only in certain parts of the field. An outstanding feature is that the two major pay lenses lie relatively low on the flanks, but do not extend across the top of the structure. Although these sands have produced much gas rich in gasoline, the oil yield has been discouraging. Two wells have produced approximately 320,000 barrels of oil of 53° A. P. I.

The Comanche series in the Cotton Valley field is represented by formations of the Trinity group and has been penetrated to a depth of 3,700 feet. The following divisions are recognized in this paper: upper Trinity red series, 270 feet; upper Glen Rose limestone and shale, 460 feet; anhydrite zone, 500 feet; lower Glen Rose limestone and shale, 1,090 feet; and lower Trinity red series, 1,390 feet. The deep Trinity formations, particularly the oil- and gas-producing sands and contiguous beds, have been extensively cored.

This paper contains a brief description of the stratigraphy, structure, and productive horizons of the Cotton Valley field. Particular reference is made to the Trinity formations, which have been studied in connection with an engineering report in preparation by the United States Bureau of Mines.

ACKNOWLEDGMENTS

The writer desires to acknowledge the help and assistance given by members of the Shreveport Geological Society, especially W. C. Spooner and A. F. Crider. H. B. Hill, United States Bureau of Mines, Dallas, Texas, reviewed this paper and gave helpful suggestions and criticisms.

[1]Read before the Association at the New Orleans meeting, March 20, 1930. Manuscript received by the editor, March 12, 1930. Published by permission of the director, U. S. Bureau of Mines.

[2]Petroleum engineer, U. S. Bureau of Mines.

LOCATION

The Cotton Valley field is located in T. 21 N., R. 10 W., Webster Parish, Louisiana, approximately 12 miles west of the Homer oil field and 40 miles northeast of the city of Shreveport.

HISTORY

Gas was discovered in the "Blossom" sand in August, 1922, and oil was found in October, 1923. An intensive drilling campaign followed, and the peak production was reached in 1925. The development of the "Blossom" sand was confined mainly to a narrow productive oil area or ring encircling the central part of the field, which contained gas. Only a small amount of the gas in the top of the reservoir was utilized. Edge water rapidly encroached upon the sand, and, in 1928, 90 per cent of the gross fluid production was water. The "Blossom" sand has produced approximately 11,500,000 barrels of low-gravity (29° A. P. I.) oil.

The first producing well in the Trinity formations was drilled by the Palmer Corporation on the Davis lease, Sec. 23, T. 21 N., R. 10 W. It was completed in the Glen Rose anhydrite gas horizon in February, 1926. Following the discovery several gas wells were drilled to the anhydrite. Production was found later in the lenticular sand zone at the top of the lower Glen Rose formation.

Development of the deeper sands was given impetus when oil was discovered during April, 1928, by the Ohio Oil Company in Bodcaw No. 38, Sec. 15, T. 21 N., R. 10 W. The initial production of this well was 3,000 - 4,000 barrels of oil per day from a sand 12 feet thick, encountered at a depth of 4,669 feet. The only important oil wells that have been completed in the Trinity formations were the Ohio's Bodcaw No. 38, and the offset, the Ohio's Bodcaw No. 39. These two wells produced approximately 320,000 barrels of high-gravity (53° A. P. I.) crude oil and then went to water.

The Magnolia Petroleum Company has drilled the deepest well in the field on the McCook-Hibbler lease in Section 22. This well was abandoned recently in the lower Trinity red series at a depth of 7,006 feet. A good showing of oil was found near the bottom of the hole.

SUBSURFACE STRATIGRAPHY

The composite geologic section of the Cotton Valley field (Fig. 1) was compiled from parts of six different wells, the Palmer Corporation's Miller No. 1, Section 29, from the surface to 2,200 feet; the Cotton Valley Syndicate's Sidney No. 1, Section 16, from 2,200 to 3,300 feet; the

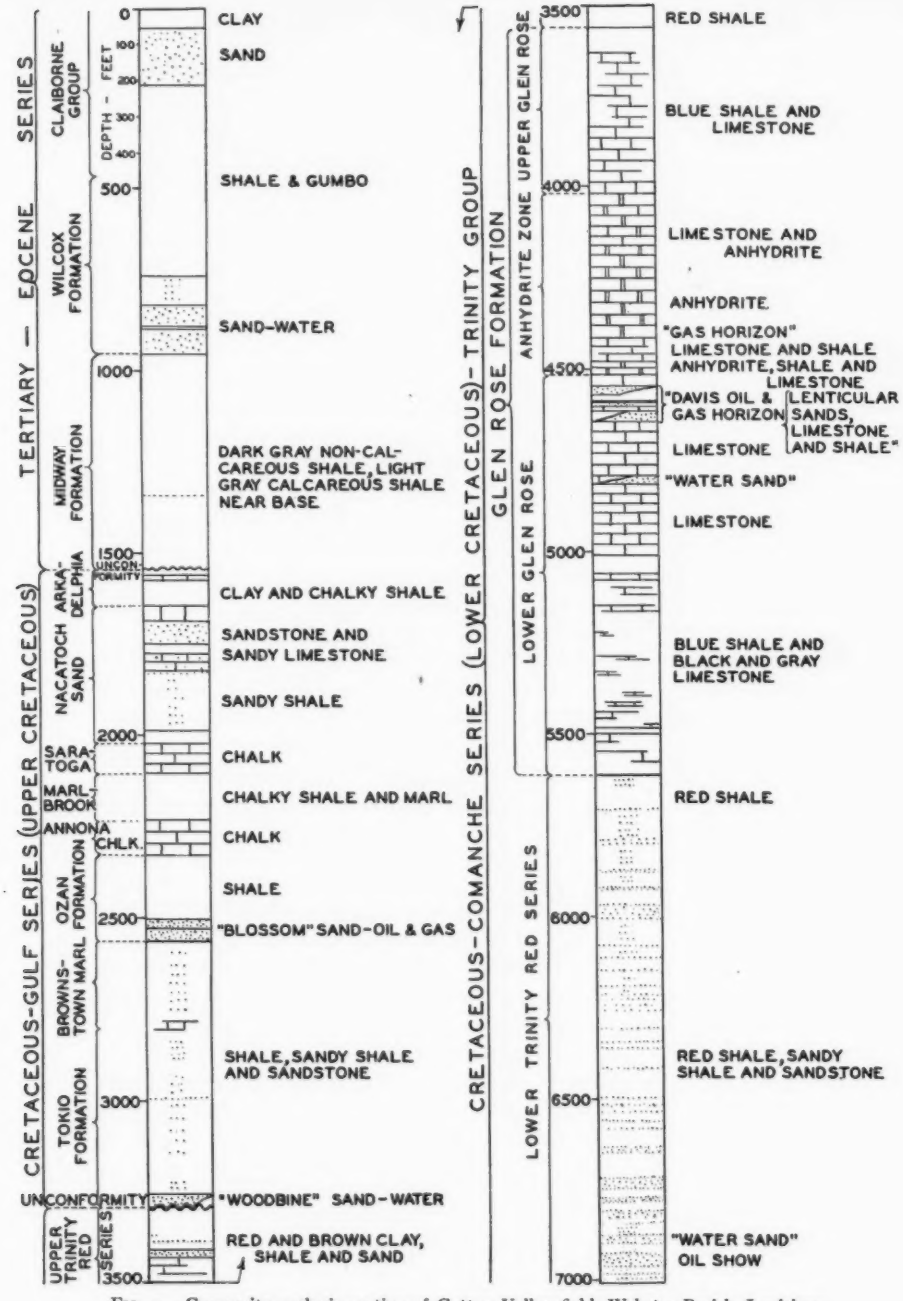


FIG. 1.—Composite geologic section of Cotton Valley field, Webster Parish, Louisiana.

Palmer Corporation's Davis No. 1, Section 23, from 3,300 to 4,000 feet; the Magnolia Petroleum Company's Ira Cox No. 3, Section 23, from 4,000 to 4,300 feet; the Magnolia's Cole No. 1, Section 27, from 4,300 to 4,650 feet; and the Magnolia's McCook-Hibbler No. 1, Section 22, from 4,650 to 7,006 feet. Continuous cores were taken of the formations below 4,300 feet.

Eocene series (Tertiary).—The Eocene Tertiary sediments are composed mainly of shale and sand. The thickness of the Eocene beds is approximately 1,550 feet. The Claiborne group is represented by beds at the surface.

Gulf series (Upper Cretaceous).—The thickness of the Upper Cretaceous section is about 1,750 feet. The Nacatoch sand is found at an average depth of 1,650 feet, but does not contain oil in the Cotton Valley field. The only sand producing oil in the Gulf series is the "Blossom," which lies 170 feet below the base of the Annona chalk.

The so-called "Woodbine" or basal sand of the Tokio formation is stratigraphically 730 feet below the top of the "Blossom" sand and, although a maximum thickness of 40 feet has been observed, it is erratic in distribution and absent in parts of the field. The sand carries water and should not be confused with a water sand lying about 100 feet below the top of the Trinity red shale.

Comanche series (Lower Cretaceous).—Approximately 3,700 feet of Comanche sediments have been penetrated in the Cotton Valley field. These sediments comprise the formations of the Trinity group, as shown in Table I.

Upper Trinity red series.—The beds of red clay, shale, and sand that comprise the upper Trinity red series in the Cotton Valley field lie unconformably below the so-called "Woodbine" sand. The thickness of the red zone ranges from about 270 feet on the top of the structure to at least 400 feet on the flanks. During the post-Comanche time interval prior to the deposition of the Upper Cretaceous beds, the Comanche sediments were elevated and folded, and the upper red series was subjected to erosion. The deep brick-red color of the shale, encountered at depths ranging from 3,200 to 3,360 feet, marks the top of the Comanche series. The upper red zone contains one water sand, in places more.

Glen Rose formation.—The Glen Rose formation in the Cotton Valley field has a total thickness of approximately 2,050 feet, and is divided lithologically into three zones, namely, upper Glen Rose, anhydrite zone, and lower Glen Rose.

TABLE I

TRINITY SECTION IN COTTON VALLEY FIELD, WEBSTER PARISH, LOUISIANA

System	*Series*	*Group*	*Formation*		*Description*	*Thickness (Feet)*
Lower Cretaceous	Comanche	Trinity	Upper Trinity red series		Red clay, shale, and sand	270-400
			Glen Rose	Upper Glen Rose	Limestone and blue shale	460
				Anhydrite zone	Anhydrite, limestone, and shale	500
				Lower Glen Rose	Limestone and blue shale	1,090
			Lower Trinity red series		Red and purplish shale and pink, red, and white sand	+1,300

The upper Glen Rose is 460 feet thick and consists of alternate beds of limestone and blue shale. The top of this formation, near the center of the field, lies at a depth of approximately 3,500 feet.

The anhydrite zone is 500 feet thick and includes all the beds of anhydrite, limestone, and shale between the top of the highest and the bottom of the lowest anhydrite bed. In the upper part of the zone, the anhydrite beds are thin and interfingered with thick limestone, making the top of the zone difficult to recognize. The beds in the lower half of the zone, however, are massive, and because of their distinctive character are easily recognized in drilling. The basal anhydrite bed, which is 40 feet thick, is separated by 65 feet of limestone and shale from a massive anhydrite bed above, approximately 100 feet thick. The bottom of the anhydrite zone makes a good marker for correlating the Trinity formations.

The lower Glen Rose formations have been penetrated in two wells drilled near the center of the field, and in both these wells a thickness of 1,090 feet was reported. The first 490 feet of the lower Glen Rose consists of massive beds of dark and light gray limestone, with subordinate beds of shale and lenticular sands. The deep pay sands in the Cotton Valley field lie near the top of these limestones. A thin sand in the middle of the limestone section carries water. Calcareous and non-calcareous shale of dark blue color predominates in the lower 600 feet, and the limestone beds are thin and argillaceous.

Lower Trinity red series.—The thickness of the beds of shale and sand of the lower Trinity red series is probably about 2,000 feet. Not all of the section, however, has been drilled in the Cotton Valley field. The deep well drilled by the Magnolia Petroleum Company on the McCook-Hibbler lease, Sec. 22, T. 21 N., R. 10 W., was abandoned at a depth of 7,006 feet after being drilled into the red beds 1,390 feet. The base of the red zone, however, was penetrated in the Pine Island field, Caddo Parish, and the Bellevue field, Bossier Parish. In the former field, according to Crider,[1] the deep test well of the Dixie Oil Company, Dillon No. 92, encountered 2,030 feet of red sediments. In the Bellevue field the lower Trinity red series is 1,900 feet thick. The beds of the red zone are presumably of non-marine origin.

One well drilled near the top of the structure in the Cotton Valley field entered the lower red beds at a depth of 5,545 feet, which is 1,650 feet deeper than the top of the same series in the Pine Island field. The top beds in the Cotton Valley field consist of red and purplish shales and pink and red sands. Deeper in the series the sands are more plentiful and lighter in color. Near the bottom of the Magnolia's McCook-Hibbler well the predominant formation consisted of white and gray sands. A sand in this well, approximately 1,250 feet below the top of the zone, was found to contain water, and sand cores below 1,300 feet were stained with oil.

Comparatively little information is available regarding the lower Trinity marine section which underlies the red series. Dixie's Dillon No. 92, in the Pine Island field, was drilled out of the lower red beds at a depth of 5,925 feet and penetrated 426 feet of dark, hard limestone, shale, and sand. The log of the formations in the lower part of this well is shown in Table II. A showing of gas and oil, but not in commercial quantities, was reported in sand from 6,119 to 6,125 feet, or 194 feet below the top of the lower Trinity marine formations. From 6,125 feet to the bottom of the hole the formations consisted of alternate beds of hard, calcareous sandstone and limestone, with subordinate beds of hard shale.

SUBSURFACE STRUCTURE

The Cotton Valley field is an anticlinal fold with an axial trend northeast and southwest. The apex of the structure is in Sec. 23, T. 21 N., R. 10 W. The Trinity formations were elevated and folded at the end of Comanche time, and again, but to a less degree, during the period

[1] A. F. Crider, "Pine Island Deep Sands, Caddo Parish, Louisiana," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929).

TABLE II

LOWER TRINITY FORMATIONS IN PINE ISLAND FIELD, CADDO PARISH, LOUISIANA

Depth in Feet at Bottom of Formation		*Depth in Feet at Bottom of Formation*	
5,925	Base of lower Trinity red zone	6,112	Dark sandy limestone and shale, fossiliferous
5,941	Gray sandy limestone		
5,962	Dark gray sandy shale	6,119	Dark limestone
5,970	Gray sandstone	6,125	Sand, showing of gas (192,000 cu. ft.) and oil
5,995	Dark slaty shale		
6,014	Dark sandy limestone	6,138	Sandy and shaly limestone
6,019	Light limestone	6,157	Limestone, fossiliferous
6,025	Dark slaty shale	6,186	Interbedded hard limestone and sand
6,034	Dark sandy limestone, fossiliferous and pyritic	6,297	Hard limestone and shale
6,050	Dark sandy shale, laminated	6,306	Hard sandy limestone
6,055	Dark sandy limestone, fossiliferous	6,316	Hard sand
		6,320	Sandy shale
6,070	Dark shale	6,323	Hard sand
6,075	Dark sandy shale	6,327	Hard shale and sand
6,110	Black shale	6,351	Hard sandy limestone and sand

of deformation of the Upper Cretaceous and Eocene Tertiary beds. Since the older beds dip much more steeply than the younger, the Trinity structure has the appearance of being elongated rather than dome-shaped, as is exemplified in the Upper Cretaceous.

The structure of the Upper Cretaceous beds is represented in Figure 2 by contours drawn on the top of the "Blossom" sand, and the structure of the Trinity formations is shown in Figure 3 by contours drawn on the base of the anhydrite zone. The "Blossom" sand structure, within the proved area of the field, has a closure of 80 feet as compared with a closure of about 220 feet for the same area in the Trinity formation.

The structural cross sections in Figures 2 and 3 were drawn on the same exaggerated scales and the sections show the relative dips of the "Blossom" sand and the anhydrite and underlying contingent beds. The unconformity between the Comanche and Upper Cretaceous beds may be observed in Figure 4, which is a cross section through the center of the field perpendicular to the structural axis.

PRODUCING HORIZONS

"Blossom" sand.—This paper deals primarily with the producing zones below the "Blossom" horizon, although the "Blossom" is the main producing oil sand in the field. The average thickness of the pay

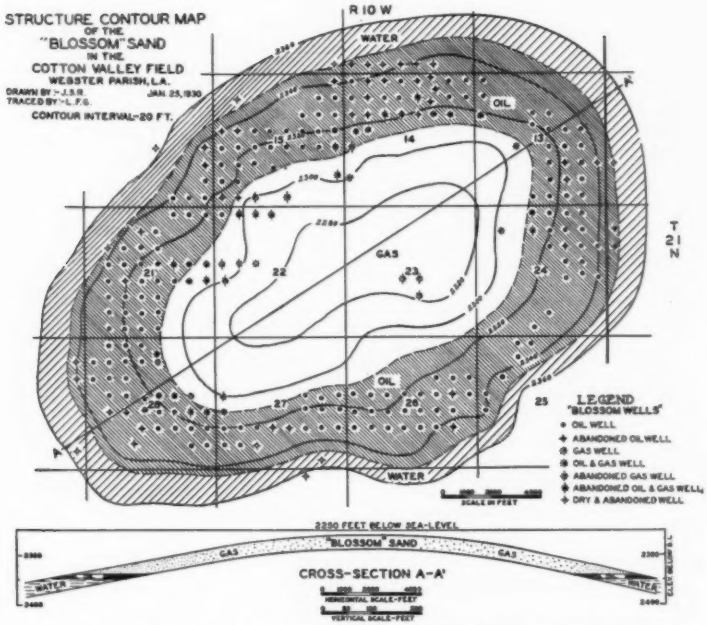


FIG. 2.—"Blossom" sand structure, showing distribution of gas, oil, and water.

sand is 30 feet, and the depths of the wells range from 2,500 to 2,600 feet. The "Blossom" sand reservoir originally contained gas, oil, and water, arranged in the order of their specific gravities and distributed throughout the field in the manner shown in Figure 2. The arrangement of fluids and gases in the dome-shaped "Blossom" sand reservoir is an ideal textbook example of segregation in an oil-field structure.

Anhydrite gas horizon.—The gas horizon in the anhydrite zone lies approximately 100 feet above the base of the zone. The gas evidently comes from porous or fractured beds of limestone and anhydrite. Cores in this formation show finely divided pyrite but no sand.

Davis horizon.—The sands which produce oil and gas in the top of the lower Glen Rose formation lie in a zone approximately 85 feet thick, 35-40 feet below the base of the anhydrite zone. This zone is designated locally as the Davis horizon, after the name of the lease on which the first well to penetrate these sands was drilled. Three minor sand zones

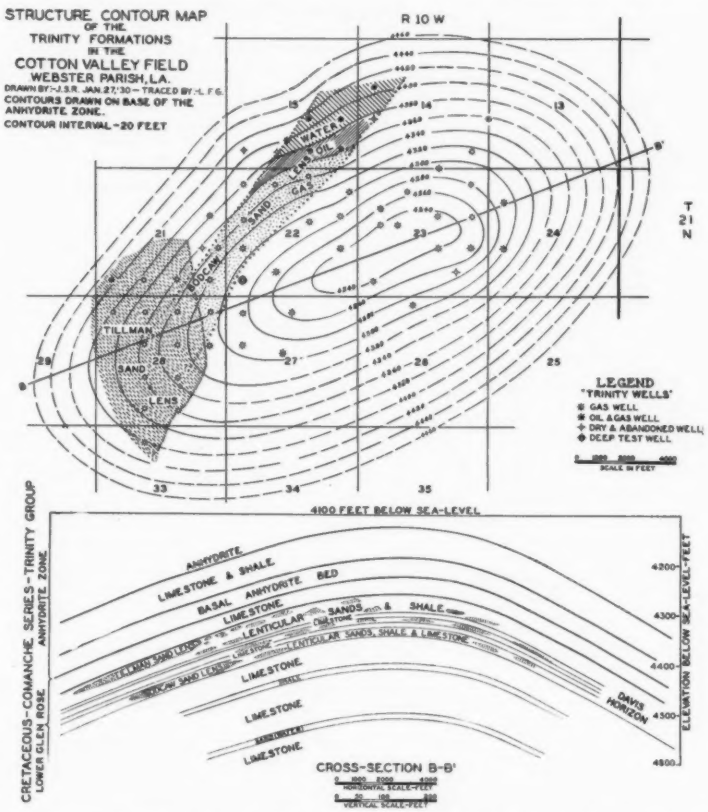


FIG. 3.—Trinity structure, with contours drawn on base of anhydrite zone, showing distribution of gas, oil, and water in the two major sand lenses.

separated by thin limestone have been recognized in wells where this horizon has been cored carefully. A representative section of the Davis horizon is given in Table III.

The sands in the Davis horizon are lenticular in structure and relatively thin. They differ widely in porosity and are erratically distributed throughout the field. Their depths range from 4,500 to 4,700 feet. Two lenses only are of major importance. One of these, the Tillman sand lens, lies at the top of the horizon; the other, the Bodcaw

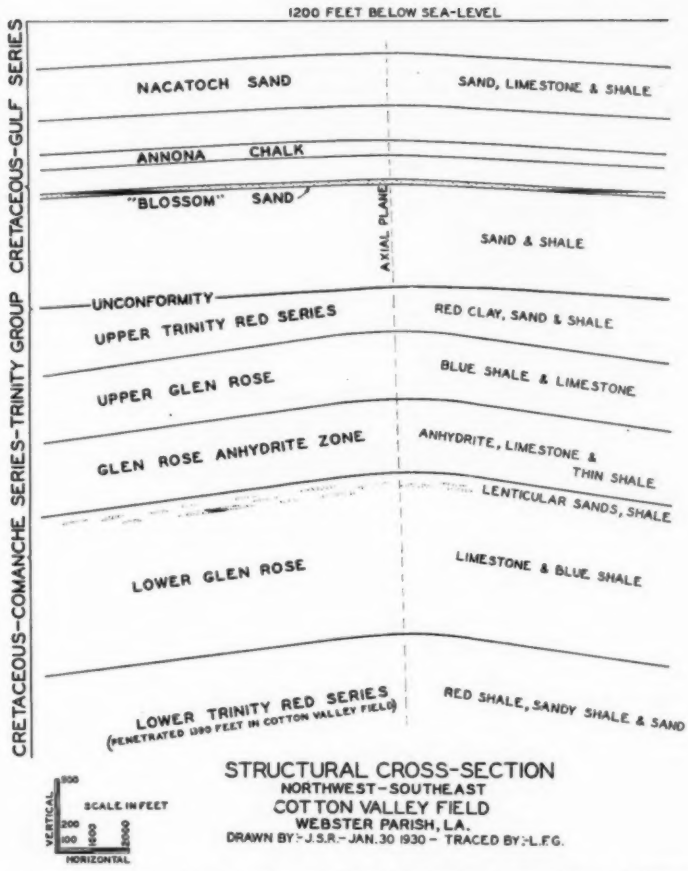


FIG. 4.—Cross section showing unconformity between Comanche and Upper Cretaceous formations.

sand lens, lies near the base of the horizon. The names of the two sand lenses were taken from the leases upon which the first producing wells were drilled.

The Tillman sand lens produces principally gas, with a small amount of oil, and as developed to date (February, 1930) extends through parts of Sections 21 and 28 in the southwest part of the field. This sand lens

TABLE III

REPRESENTATIVE SECTION OF BASAL ANHYDRITE BED AND DAVIS OIL AND GAS HORIZON, COTTON VALLEY FIELD, WEBSTER PARISH, LOUISIANA

Magnolia Petroleum Company's J. M. Mixon No. 1, Sec. 22, T. 21 N., R. 10 W.

		Depth in Feet at Bottom of Formation	
Basal bed of the anhydrite zone	Key horizon	4,490-4,518	Anhydrite
		4,532	Anhydrite, calcareous shale, and argillaceous limestone
		4,568	Gray limestone and calcareous shale
Lower Glen Rose		4,576	Pale green and gray fine-grained sandstone, and calcareous and argillaceous sandstone
		4,589	Reddish brown and green non-calcareous shale
		4,595	Pale green fine-grained, and rusty coarse-grained sandstone
	Davis oil and gas horizon	4,601	Hard blue shale
		4,609	Gray limestone, fossiliferous
		4,616	Dark gray, fine-grained sandstone, carbonaceous
		4,619	Shale
		4,629	Gray limestone, fossiliferous, and calcareous shale
		4,652	Brown and light gray, fine- and coarse-grained sandstone, and calcareous sandstone
		4,658	Gray, calcareous sandstone and limestone

ranges in thickness from a few feet to about 20 feet. Its areal distribution is shown on the structure map in Figure 3.

The Bodcaw sand lens as outlined by drilled wells is a narrow, lenticular sand ranging from ¼ to ½ mile wide, extending northeast and southwest across the northwest side of the field. The thickness of this sand lens ranges from a few feet to approximately 25 feet. The interval between the top of the Bodcaw sand and the base of the anhydrite zone is approximately 100 feet. The interpreted positions of the gas, oil, and water and the areal distribution of the sand are outlined on the map (Fig. 3).

Most of the wells that have penetrated the Davis horizon were drilled on the crest and on the north and west sides of the structure. The failure of the wells on the top of the structure to encounter large sand bodies comparable with the Tillman and Bodcaw sand lenses does

not condemn the areas lying on the south and southeast sides of the structures, in which no deep wells have been drilled. There is possibility, however, that these areas may contain, low on the structure, productive sand lenses of the type mentioned. Thin sands were encountered near the apex which produced large initial flows of gas.

Possible deeper horizons.—The deepest pay sands developed in the Cotton Valley field are approximately 4,600 feet deep. The formations below these sands have been penetrated 2,400 feet and, although showings of gas and oil were encountered at several horizons, none of the sands proved to be productive; hence, the possibilities of deeper production seem to be limited to the older beds of the red series and the marine formations of the lower Trinity. These beds lie below the approximate depth of 7,000 feet.

In the deep test well, the Magnolia's McCook-Hibbler No. 1, Section 22, several oil-stained sands were cored between the depths of about 6,900 and 7,000 feet. At 6,945 feet, or 1,330 feet below the top of the lower Trinity red section, a 13-foot core was taken of a sand which contained considerable free oil. A string of 5¾-inch casing was cemented at 6,947 feet, but when the casing was bailed, water from behind the casing, or from the sand, entered the hole as rapidly as it was bailed, and prevented a satisfactory test. The well then was deepened from 6,958 to 7,006 feet and was abandoned.

The presence of oil stains in the sands of the lower Trinity red series is of special significance because this presumably non-marine section has not generally been considered favorable for oil and gas accumulations.

The lower Trinity marine beds probably underlie the red zone in the Cotton Valley field. The possibility that this formation contains oil and gas is suggested by the oil and gas showings found in the Pine Island deep test well, Dillon No. 92.

CONCLUSION

The production in the Trinity group in the Cotton Valley field is found principally in lenticular sands approximately 1,250 feet below the top of the Comanche beds and 2,000 feet below the "Blossom" sand.

Commercial gas has been found in the anhydrite zone approximately 100 feet above its base.

The anhydrite zone, which is 500 feet thick, is the most dependable key horizon in the Trinity section and should be logged carefully. The basal beds of the anhydrite zone are more massive than the top beds; therefore, they are more easily recognized. If the base of the zone is

accurately established by coring, detailed correlation of the several lenticular sands lying below is simplified.

The lenticular sands which comprise the Davis horizon differ greatly in porosity. The porosity of the sand is very important and evidently the production of a well depends to a large extent upon this characteristic. It may be observed in Figure 3 that neither the Tillman nor the Bodcaw sand lens traverses the top of the structure. The possibility of production from lenticular sands lying on the flanks of a fold, and not penetrated by wells drilled on the top, is an important feature which should receive proper consideration in future prospecting on the Trinity "highs."

GEOTHERMAL VARIATIONS IN OIL FIELDS OF LOS ANGELES BASIN, CALIFORNIA[1]

ANDERS J. CARLSON[2]
Berkeley, California

ABSTRACT

Data obtained from temperature measurements in oil wells of the Los Angeles basin are presented, and some causes of abnormal temperature conditions and factors affecting the interpretation of geothermal data are noted. The relations of geothermal gradients and isothermal depths to structure are discussed for the Santa Fe Springs, Long Beach, and Torrance fields. Variations in the geothermal constants are considered with respect to the geology of the region, and the possible correlative value of temperature data is suggested.

EVALUATION OF GEOTHERMAL DATA

The determination of oil-well temperatures in California under the auspices of the American Petroleum Institute has included rather complete surveys of the Santa Fe Springs and Long Beach fields, a partial survey of the Torrance field, and tests of a few wells in several other areas. In evaluation of the possible local and regional significance of the data, three important factors affect the conclusions obtained, namely, the accuracy of the measured data, the bases upon which comparisons of the various units of data are made, and the actual subsurface thermal conditions as represented by the temperatures in each well. These factors should receive brief mention.

Accuracy of measured data.—The accuracy of measurement is dependent chiefly upon apparatus and technique and can be controlled within certain limits. The work of other investigators and check measurements by the writer have demonstrated the reliability of maximum mercury thermometers supported from a hand reel or on a rig cable. A

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, March 12, 1930. This paper contains results obtained in an investigation on "Determination of Geothermal Gradients in Oil Fields on Anticlinal Structure," listed as Project No. 25-C of American Petroleum Institute Research. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by The Universal Oil Products Company. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. Lester C. Uren is director of the project.

[2]Lecturer in petroleum engineering, University of California; junior research fellow, American Petroleum Institute. Introduced by F. H. Lahee.

precision of about 0.2° F. is attainable, which at present seems to be quite sufficient. The most serious limitation in the use of thermometers is the intermittent nature of the measuring procedure and the consequent consumption of time. However, more rapid continuous methods, involving elaborate equipment, have not been perfected sufficiently to justify their use in this work.

Bases of comparison.—Isothermal depths and geothermal gradients have been commonly employed for the comparison of well-temperature data. These are computed constants representing the variation of temperature with depth, and their refinement depends upon the amount and precision of the data available. The isothermal depths may preferably be converted to isothermal elevations by taking account of the surface elevation at each well, thus reducing the location of isotherms to a common datum. The reciprocals of the geothermal gradients may be used so as to treat with whole numbers rather than decimals.

For the fields included in this investigation the isothermal depths have proved more reliable than the gradients in picturing geothermal variations. This may be attributed to inherent differences in the derivation of the constants and to the natural or artificial temperature abnormalities existing in these areas.

If the temperature data of a well are represented graphically, the resulting depth-temperature curve has normally a slight curvature and the gradient varies somewhat uniformly with depth. The isothermal depth is determined by interpolation between two measured depth-temperature values. The mean gradient for a certain depth interval is derived by the method of least squares,[1] on the assumption that the depth-temperature curve closely approximates a straight line. It is evident that the comparative significance of the computed gradients would be most seriously affected by abnormal temperatures which would cause the curves to exhibit differing degrees of divergence from the normal.

The erratic gradients in California fields are due at least partly to the abnormal shallow temperatures characteristic particularly of the Santa Fe Springs field. The curves exhibit a markedly sharper curvature for the first 500-1,000 feet of depth than for the greater depths. In the attempt to reduce the gradients to a comparable basis, they have been computed through certain standard depth intervals; only temperatures at certain standard depths were used; any obviously abnormal

[1] C. E. Van Orstrand, "Some Evidence on the Variation of Temperature with Geologic Structure in California and Wyoming Oil Districts," *Econ. Geol.*, Vol. 21, No. 2 (March-April, 1926), pp. 145-65.

temperatures were eliminated. Similarly, the 100° isotherm was used for comparisons, as in this district it occurs at depths below 1,000 feet.

Actual thermal condition.—Of the three factors mentioned, the actual subsurface thermal condition as represented by the measured temperatures is the most important, but the most difficult of definition. Natural rock temperatures should reflect most accurately the geothermal variations which are sought in this study. It may be assumed that such temperatures will be most closely approached in a well when a condition of thermal equilibrium exists. The extent to which a well is removed from such condition at the time of measurement becomes, therefore, an essential consideration in the evaluation of the data.

The writer has previously discussed[1] the extent to which disturbing influences are reflected in various forms of depth-temperature curves. Temperatures controlled by natural causes may be abnormal, yet may represent true rock temperatures. These abnormalities can not be eliminated, but must be disregarded entirely or taken into account in the mathematical treatment. Abnormalities due to artificial disturbances may presumably be eliminated by leaving the well idle for a sufficient period before measurement. Where rotary drilling, flowing, or pumping has been going on for a considerable time, a year or more of inactivity may be required to reëstablish the natural condition. This emphasizes the need of further study of typical depth-temperature curves so that the magnitude of the discrepancies between measured temperatures and true rock temperatures may be estimated. Meanwhile, the lack of exact definition of the condition of all wells in terms of common criteria must be recognized in discussing the seeming significance of geothermal variations in some areas.

VARIATION OF GEOTHERMAL CONSTANTS WITH STRUCTURE

Temperature data from eighty-three wells have been obtained in the Santa Fe Springs, Long Beach, and Torrance fields. Data for eighteen of these were furnished by C. E. Van Orstrand, and the remainder were measured by the writer. Table I shows a classification of the wells with respect to type and period of idleness before measurement.

RECIPROCAL GRADIENTS

In these three fields the variations or reciprocal gradient values for the depth interval between 100 and 2,000 feet do not indicate a definite trend with respect to structure. There are two chief causes

[1] "Geothermal Conditions in Oil Producing Areas of California." Unpublished report to American Petroleum Institute (November, 1929).

TABLE I

Class	Type (Idle one year or more)	Number of Wells		
		Santa Fe Springs	Long Beach	Torrance
1	Non-producers, outside producing area	1	..	..
2	Non-producers, within producing area	1	3	..
3	Producing some oil	11	14	3
4	Gas producers	2	..	..
	(Idle less than one year)			
5	Regular producers, lately on pump	13	14	4
6	Drilling wells	2	3	..
7	Water wells	3	4	..
8	Non-producers, within producing area	..	5	..

which may account for this to a large extent. One is the variation of the reciprocal gradients within the narrow limits of a few feet per degree of temperature. The other is the seeming absence of natural rock temperatures in several wells measured. A third may be of importance, namely, the exceptional development of the Santa Fe Springs and Long Beach fields, involving close spacing of wells and extended flow of wells under high pressure. A fourth, which is particularly noticeable in the Santa Fe Springs field, is the abnormal variation of shallow temperatures, probably due to the circulation of ground waters.

As to a general increase or decrease in reciprocal gradients from the flanks to the crest of a structure, the evidence is about equally divided at Santa Fe Springs. At Long Beach the reciprocal gradients show a somewhat more uniform variation with a general decrease in values toward the crest of the structure. At Torrance there is a lack of definite trend among the few wells measured.

ISOTHERMAL ELEVATIONS

The isothermal elevations exhibit a somewhat more reliable and satisfactory picture of the geothermal variations. Figures 1, 2, and 4 are subsurface contour maps of the three fields here mentioned. Each map shows elevations at the different wells and approximate elevation contours for the 100° F. isothermal surface.

Santa Fe Springs.—In the Santa Fe Springs area (Fig. 1) it will be noticed that the isothermal elevations below sea-level show a general decrease from west to east; in other words, the isothermal surface rises from west to east. The form of the surface indicated by the contours

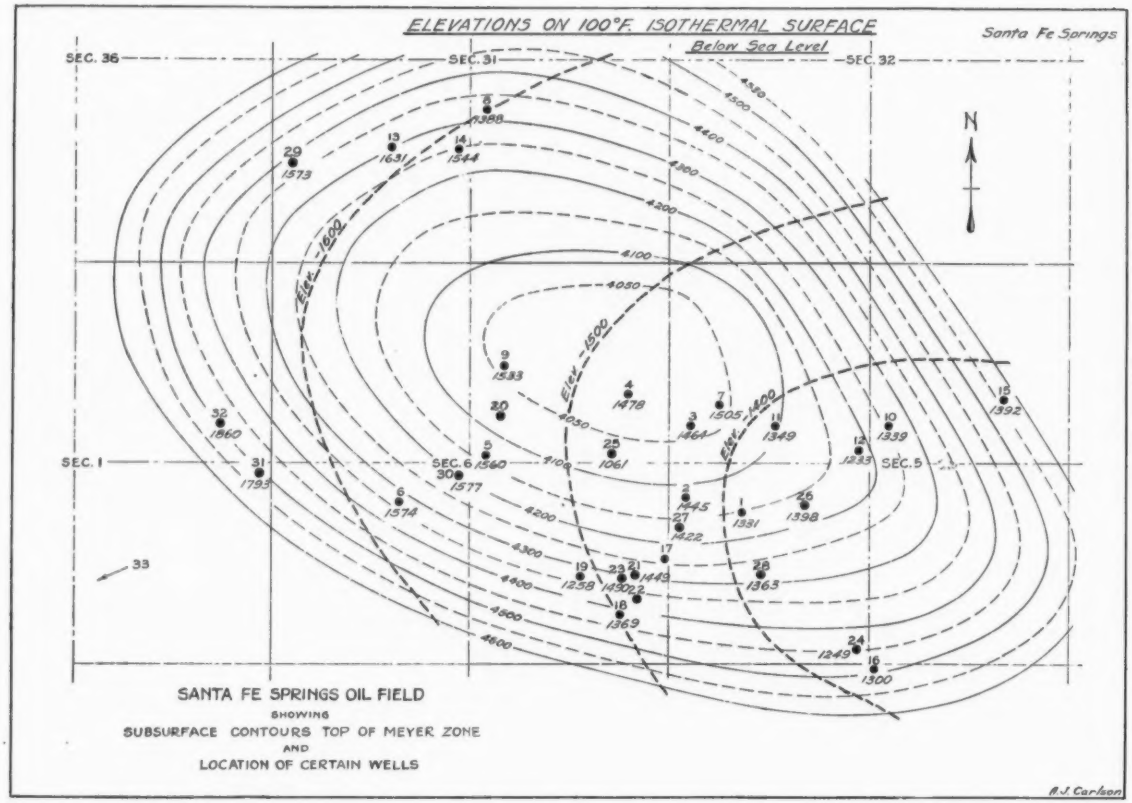

ELEVATIONS ON 100°F. ISOTHERMAL SURFACE
Below Sea Level
Santa Fe Springs
SEC. 36
SEC. 31
SEC. 32
SEC. 1
SEC. 6
SEC. 5
N
Elev. -1600
Elev. -1500
Elev. -1400
4500
4400
4300
4200
4100
4050
SANTA FE SPRINGS OIL FIELD
SHOWING
SUBSURFACE CONTOURS TOP OF MEYER ZONE
AND
LOCATION OF CERTAIN WELLS
R.J. Carlson

FIG. 1

drawn is not well defined by the elevations, but is assumed so as to conform most closely with apparent segregation of values. Of the 29 wells for which values are shown, 21 show an approximate conformity with the assumed surface, and 8 are distinctly at variance from it.

These results may be interpreted as indicative of, but not as acceptable evidence of, a relation between isotherms and structure. The trend of the isothermal surface is unmistakable, but there is little proof that this can be attributed to the anticlinal oil accumulation. Because of the temperature abnormalities existing in this field, it is doubtful if any treatment of the data can be entirely conclusive.

Long Beach.—In the Long Beach area (Fig. 2) the isothermal surface shows a general conformity with the structure. Of the 40 wells for which values are shown, 33 conform approximately with the surface defined and 7 are at variance from it.

The differences in ground-surface elevations in this field are appreciable, and it is not obvious from this representation on a plan map whether the isothermal surface is related to the anticlinal structure, or whether it is simply a reflection of surface topography. To present the possible relation more clearly, Figure 3 shows a vertical section near the longitudinal axis of the field passing through thirteen wells as indicated on Figure 2. Traces of the isothermal surfaces at 10° intervals, the ground surface, and the lower Brown zone are shown for comparison.

Two features are evident from an inspection of this figure: the variation of the isothermal elevations seems to conform with the outline of the ground surface rather than with the outline of the oil-bearing strata, and the vertical range of elevations on each isotherm becomes less as the depth increases. This latter condition is strikingly verified in Table II, which shows the total difference in elevation on each isotherm as computed from the data of the thirteen wells.

TABLE II

	Total Difference in Elevation, in Feet
Ground surface	296
80° isotherm	492
90° isotherm	348
100° isotherm	274
110° isotherm	223
120° isotherm	182
130° isotherm	200
140° isotherm	141
Lower Brown zone	1,100

With the exception of the 130° isotherm, the differences are progressively less with greater depth. It is to be noticed that the difference

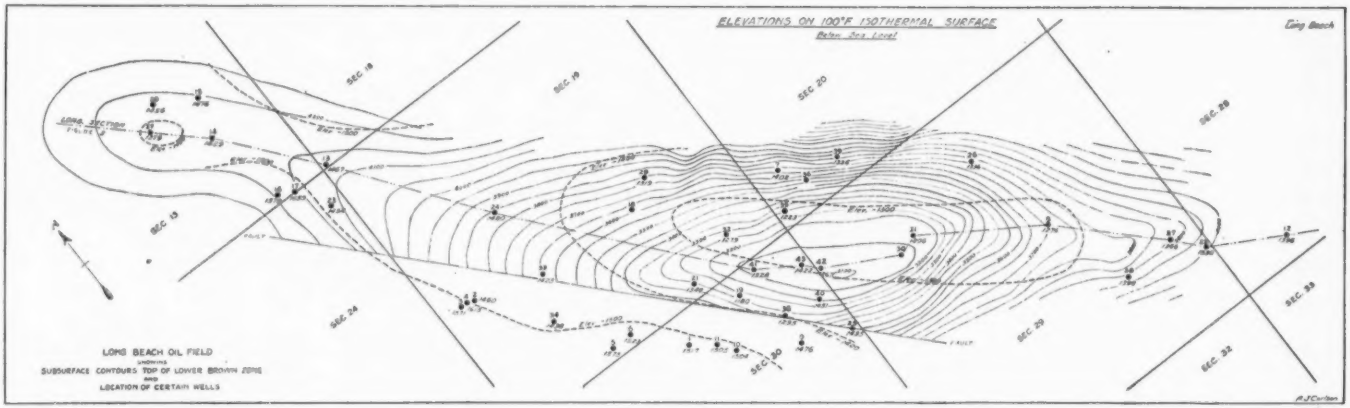

ELEVATIONS ON 100°F ISOTHERMAL SURFACE
Below Sea Level
Long Beach
SEC. 18
SEC. 19
SEC. 20
SEC. 21
SEC. 13
SEC. 24
SEC. 29
SEC. 30
SEC. 32
SEC. 33
LONG BEACH OIL FIELD
SHOWING
SUBSURFACE CONTOURS TOP OF LOWER BROWN ZONE
AND
LOCATION OF CERTAIN WELLS
R.J.Carlson

FIG. 2

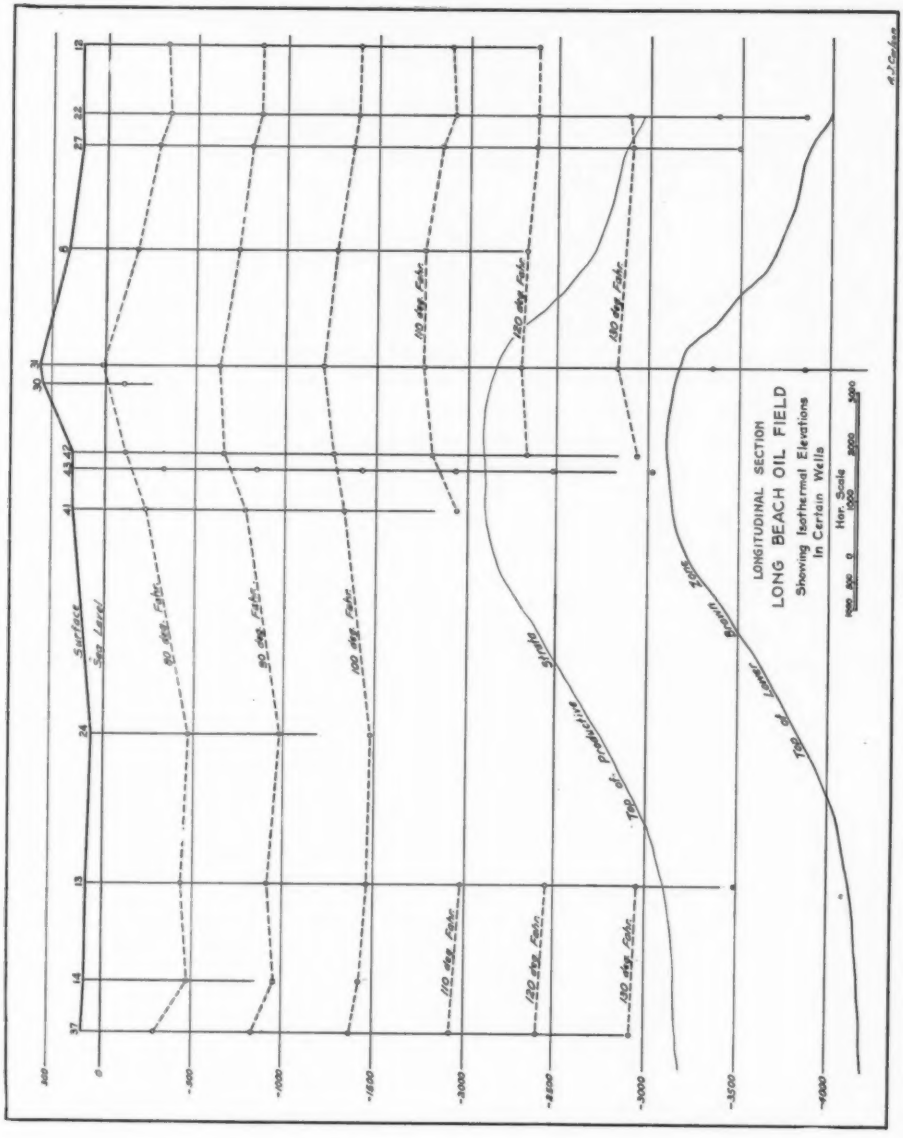

LONGITUDINAL SECTION
LONG BEACH OIL FIELD
Showing Isothermal Elevations
In Certain Wells
Hor. Scale
Surface
Sea Level
120 deg. Fahr.
Top of productive strata
Top of Lower Pleistocene
A. J. Carlson

FIG. 3

for the 100° isotherm corresponds closely with that for the ground surface, with increasing differences above and decreasing differences below this isotherm. This leads to the conclusion that the temperatures in this field are not governed by topography and a normal flow of heat toward the ground surface.

According to Van Orstrand,[1] if normal cooling is assumed, the isotherms below a peak are always flatter than the topographic surface above them. For the shallow isotherms such a condition is not indicated in Table II, as they show greater differences of elevation than that given for the ground surface. However, it is to be noticed that, of the wells on the section, those having the maximum reciprocal gradients are nearest the topographic peak and consequently nearest the structural center of the field. The same is true of well 37, near the center of the northwest extension. This relation is not in agreement with the writer's previous statement that there is a general decrease in the reciprocal gradients toward the center of the structure.

The explanation of this discrepancy seems to be that the obvious abnormal temperature condition is an expression of lack of thermal equilibrium in several wells, and not evidence of exceptional depth-temperature relations inherent in an oil-bearing structure. This is substantiated by the fact that wells 37, 41, 42, 31, and 8 are pumping wells with short periods of idleness in which true rock temperatures were probably not established. It is further verified by the location of the isotherms in well 43, which is a small producer with a long period of idleness.

This study indicates the extent to which artificial well temperatures may affect interpretation of the data. The seeming relation of isotherms to structure shown on the section can not be accepted on the basis of the evidence at hand, but must be further developed by supporting data.

Another interesting feature is that the form of an isotherm seemingly is not affected in passing from non-productive to productive strata. This is best illustrated in the 120° isotherm and is further indicated by a comparison of the elevations of the deeper isotherms in wells 22 and 31. There is a rise of only 5 feet in elevation of the 150° isotherm from well 22 to well 31.

Torrance.—The measurements in the Torrance field (Fig. 4) were not originally sought to develop the geothermal relations in that area, but, rather, as a contribution to the study of the entire basin. The presence of very heavy oil made the manipulation of the thermometers

[1] C. E. Van Orstrand, "On the Nature of Isogeothermal Surfaces," *Amer. Jour. Sci.*, Vol. 15 (June, 1928), pp. 495-519.

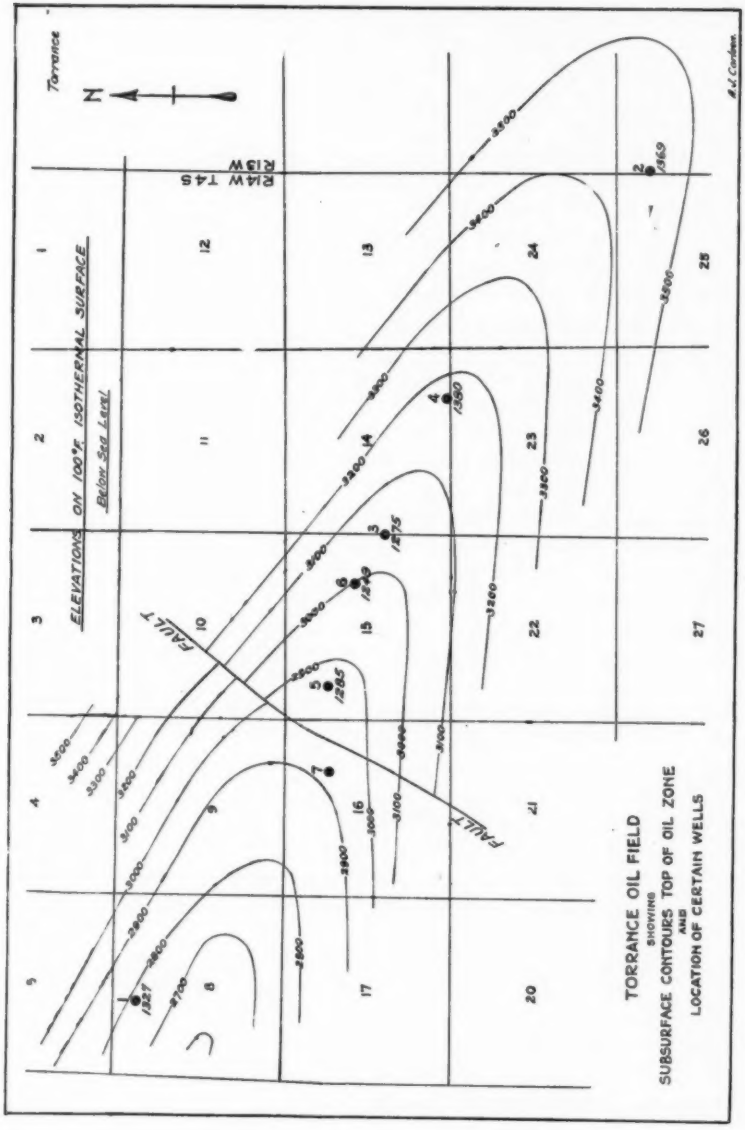

Torrance
N
R14W T4S
R13W
ELEVATIONS ON 1000'F. ISOTHERMAL SURFACE
Below Sea Level
FAULT
FAULT
TORRANCE OIL FIELD
SHOWING
SUBSURFACE CONTOURS TOP OF OIL ZONE
AND
LOCATION OF CERTAIN WELLS
M. of Cordova

FIG. 4

practically impossible below the fluid level in most of the wells. Small quantities of gas rising slowly through the oil no doubt warmed the upper portions of the fluid and maintained artificial temperature conditions in three of the wells.

In the six wells measured to appreciable depths (excluding No. 7), the 100° isothermal elevations do not show a consistent variation with the structure. In wells 1, 4, and 5, with long periods of idleness, the values show a rise in the isotherm from each end to the center of the producing area. This does not agree with the structure, which rises uniformly from east to west. Rather, it may denote a rise in the isotherm as it approaches the fault zone which intersects the structure transversely as shown in Figure 4. However, the number of measurements is not sufficient to warrant a definite conclusion to that effect.

REGIONAL VARIATION OF GEOTHERMAL CONSTANTS

The purpose of these measurements has been to make complete studies of certain fields. Consequently, the data are not sufficiently distributed throughout the basin to furnish any considerable information as to the regional variation of the geothermal constants. However, with the inclusion of a few data in the West Coyote and Whittier fields, furnished by Van Orstrand, interesting comparisons may be made.

Figure 5 shows the location of the oil fields and some of the major surface features of the Los Angeles area. Geologically, the central part of the basin consists chiefly of relatively flat Tertiary beds of great thickness. They are overlain by several hundred feet of Quaternary deposits, and underlain by some Cretaceous sediments and a basement of Jurassic or earlier metamorphic and intrusive rocks. The surrounding hills, representing areas of considerable folding and faulting, consist chiefly of a complex structure of the same series.

Table III represents the temperature data in the form of high, low, and mean values for the computed constants in the several fields. A few wells giving insufficient or very abnormal data are excluded.

The most noticeable items are the low values of both constants for the Torrance field, indicating relatively high subsurface temperatures in that area. The obvious explanation of this condition is the thinness of the Tertiary beds. The depth to the basement has been assumed here as ranging from 5,000 to 6,000 feet, whereas in the central part of the basin it has been estimated as ranging from 10,000 to 20,000 feet. The cropping out of the Tertiary formations in the San Pedro hills on the south and the position of the field on the southwestern edge of the basin

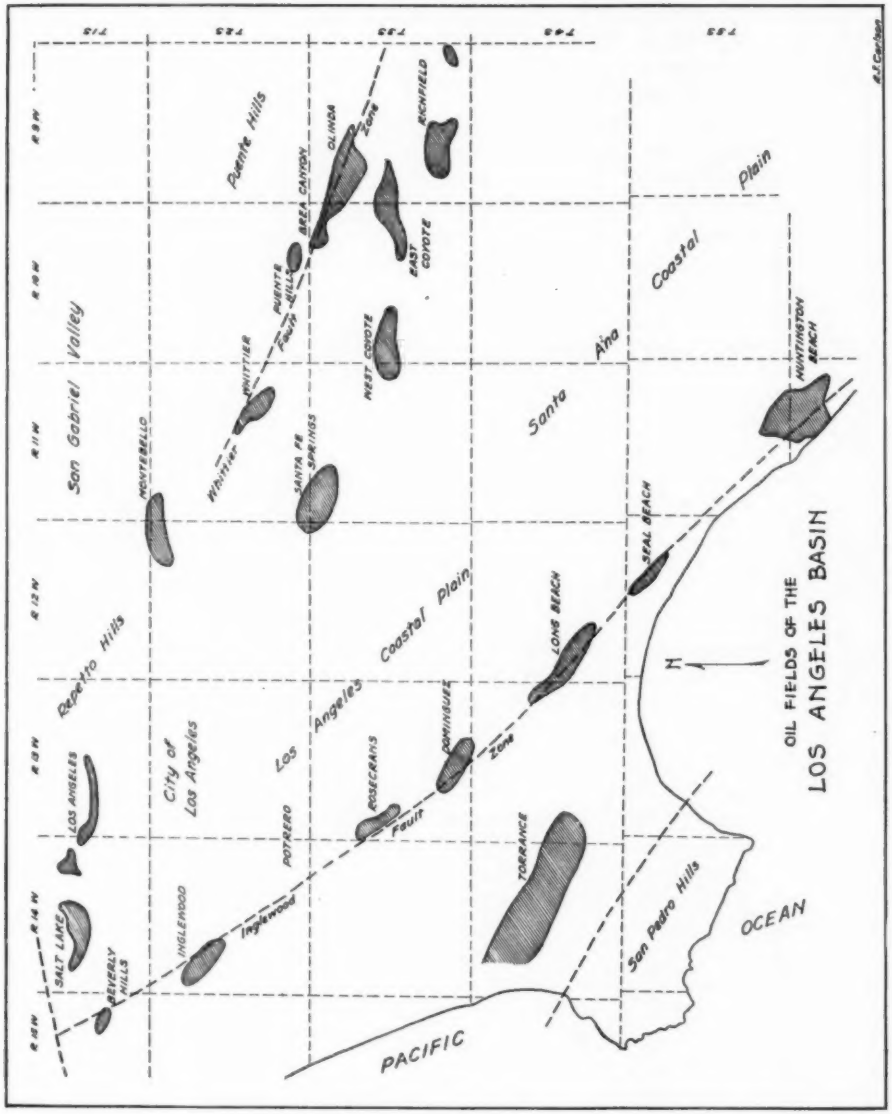

OIL FIELDS OF THE
LOS ANGELES BASIN
Puente Hills
San Gabriel Valley
Coastal Plain
Santa Ana
Repetto Hills
City of Los Angeles
Los Angeles
Coastal Plain
San Pedro Hills
OCEAN
PACIFIC
Whittier Fault
Inglewood Fault
Newport-Inglewood Zone
Palos Verdes Hills
Montebello
Whittier
Puente Hills
Brea Canyon
Olinda
Richfield
East Coyote
West Coyote
Santa Fe Springs
Huntington Beach
Seal Beach
Long Beach
Dominguez
Rosecrans
Potrero
Torrance
Inglewood
Beverly Hills
Salt Lake
Los Angeles
N

FIG. 5

TABLE III

	Wells Measured		Reciprocal Gradients			Isothermal Depths in Feet		
	Total	Excluded	High	Low	Mean	High	Low	Mean
Santa Fe Springs	33	5	55.7	47.5	50.6	1,990	1,394	1,608
Long Beach	43	4	60.0	48.5	53.7	1,669	1,375	1,534
Torrance	7	1	43.1	40.4	42.2	1,489	1,357	1,415
West Coyote	4	..	54.9	48.3	52.0	1,543	1,362	1,478
Whittier	2	1	....	....	52.8	....	....	1,620

seem to substantiate such an assumption. The high temperature can not be attributed to the presence of thick oil-bearing sediments, as the Torrance field has only one producing zone, which is thin as compared with those of Santa Fe Springs and Long Beach.

As yet, no definite relation has been developed with respect to the fault zones. There is some indication of an effect on the geothermal conditions southwest of the fault in the Long Beach field, but this can not be established because of incomplete data on the structure. The variations at Torrance are not sufficiently pronounced or consistent to be significant with respect to the transverse fault. Although the Whittier field is close to the major Whittier fault zone, the single well there shows no exceptional values.

The approximate elevations of the 100° isotherm in the several fields seem to be suggestive of a regional trend. Approximate elevations of the isotherm, found by combining the mean isothermal depths with the approximate mean surface elevations, are shown in Table IV.

TABLE IV

	Mean Depth 100°F. Isotherm in Feet	Approx. Mean Surface Elev. in Feet	Approx. Elev. 100°F. Isotherm in Feet
Santa Fe Springs	1,608	150	−1,458
Long Beach	1,534	100	−1,434
Torrance	1,415	100	−1,315
West Coyote	1,478	400	−1,078
Whittier	1,620	600	−1,020

According to these figures, the isothermal surface rises from the central part of the basin (represented by the Santa Fe Springs and Long

Beach fields) toward the southwest (represented by the Torrance field) and toward the northeast (represented by the Whittier field). This leads to the conclusion that the isothermal elevations vary with the thickness of the sedimentary beds, which are seemingly thickest in the central part of the basin. It might also be predicated that they vary to some extent with the surface elevations, which show an appreciable rise in the hills on the southwest and northeast boundaries of the basin.

A comparison of the Santa Fe Springs and West Coyote isotherms tends to corroborate these conclusions as well as to substantiate the interpretation of the data at Santa Fe Springs. The isothermal elevations in this field define a surface rising toward the southeast, as shown by the approximate contours in Figure 1. In the West Coyote field, at the southeast, the mean isothermal elevation is 438 feet higher than that at Santa Fe Springs, and the ground surface is approximately 250 feet higher. The Quaternary deposits are absent on the Coyote Hills, and presumably the Tertiary beds are somewhat thinner than at Santa Fe Springs. These conditions give some specific support to the more general evidence of a variation in isothermal elevations with respect to thickness of sediments and topography.

SUMMARY

The results of the temperature measurements here discussed indicate the need of more exact criteria for the evaluation of geothermal data. The most important factor in such evaluation is the extent to which the thermal conditions in the several wells diverge from a standard assumed condition. The significance attributed to variations of the computed constants depends largely upon how definitely such deviations can be recognized and reduced to a comparable basis by mathematical treatment.

Reciprocal gradients vary within fairly narrow limits and give only doubtful confirmation of the theory of a relation of gradients and anticlinal structure. Conditions which seemingly tend to obscure this relation are the absence of thermal equilibrium in many wells, abnormal shallow temperatures, exceptional development of the fields, and surface topography.

Isothermal depths define an isothermal surface which exhibits a general conformity with structure in the Long Beach field, but which shows a general upward trend toward the southeast in the Santa Fe Springs field. A sectional study of the Long Beach field shows a flattening of the isothermal surfaces with increasing depth and suggests that the form of

the isothermal surfaces is a reflection of artificial temperature conditions and surface topography rather than subsurface structure.

A regional variation is evident in the elevations on an isothermal surface. The trend seems to be related to the thickness of the sedimentary strata and to the major changes in surface topography. This is confirmed by the relatively high temperatures in the Torrance field, the rise of the isothermal surface from the center to the boundaries of the basin, and the agreement of the isothermal elevations in the West Coyote field with the surface established in the Santa Fe Springs field.

Evidently these results do not establish any certain correlation between geothermal variations and individual structures. However, they do show some agreement in their relation to the major geologic features of the basin. Because of the disturbing conditions summarized, the conclusions must be considered as tentative, to be reviewed repeatedly in the light of new information. No doubt, additional data and further study of their interpretation either will lead to more positive conclusions as to the possible effect of anticlinal structures on rock temperatures or will show that the effects of other geologic and topographic features are of such magnitude as to preclude the establishment of any definite relations.

GEOLOGY OF VERMILION CREEK GAS AREA IN SOUTHWEST WYOMING AND NORTHWEST COLORADO[1]

W. T. NIGHTINGALE[2]
Rock Springs, Wyoming

ABSTRACT

The Vermilion Creek gas area, located on both sides of the state line between southwest Wyoming and northwest Colorado, is now the field terminus of a 330-mile $20,000,000.00 gas line built in 1929 and supplying Salt Lake City, Utah, and adjacent towns with natural gas. The gas developed here is the first important commercial gas developed in the Tertiary formations of the Rocky Mountain region.

Six closed domes, three of which are associated with considerable faulting and four of which are controlled by one main line of anticlinal folding, are developed. The folding in the gas area is a direct consequence of the older and more severe regional structural movements in the Uinta Mountains on the south and west and the Rock Springs uplift on the northwest.

To date two of the domes have been proved for commercial gas, one well yielding a total of 65,000,000 cubic feet per day from four separate sands. The gas is produced from irregular sand bodies, very lenticular and physically different, in the lower Wasatch formation of Eocene Tertiary age. The producing horizons are of fresh-water origin only.

Gas accumulation is controlled by the folding of the Tertiary beds into closed structures.

The source of the gas, which is of excellent quality, is not exactly known. Examination of outcrops and of drill cuttings reveals comparatively scanty evidence of organic life in the lower Tertiary beds. It has been suggested that the underlying Cretaceous beds are the source, but the preponderance of evidence does not support this view.

Production from the gas area commenced in September, 1929. Insufficient gas has been run to date to make possible accurate estimates on the life of wells and total reserves.

LOCATION

The Vermilion Creek gas area comprises 250 square miles in the southern part of Sweetwater County in southwest Wyoming, and the northern part of Moffat County in northwest Colorado. More exactly it lies in T. 12 and 13 N., R. 99, 100, and 101 W. of the Sixth Principal Meridian in Wyoming and in T. 11 and 12 N., R. 100 and 101 W. of the same meridian in Colorado (Fig. 1). The southwest limit of this area is not more than 6 miles from the corner junction of the states of Colorado

[1]Read by title before the Association at the New Orleans meeting, March 22, 1930. Manuscript received by the editor, March 20, 1930.
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[2]Geologist, Mountain Fuel Supply Company.

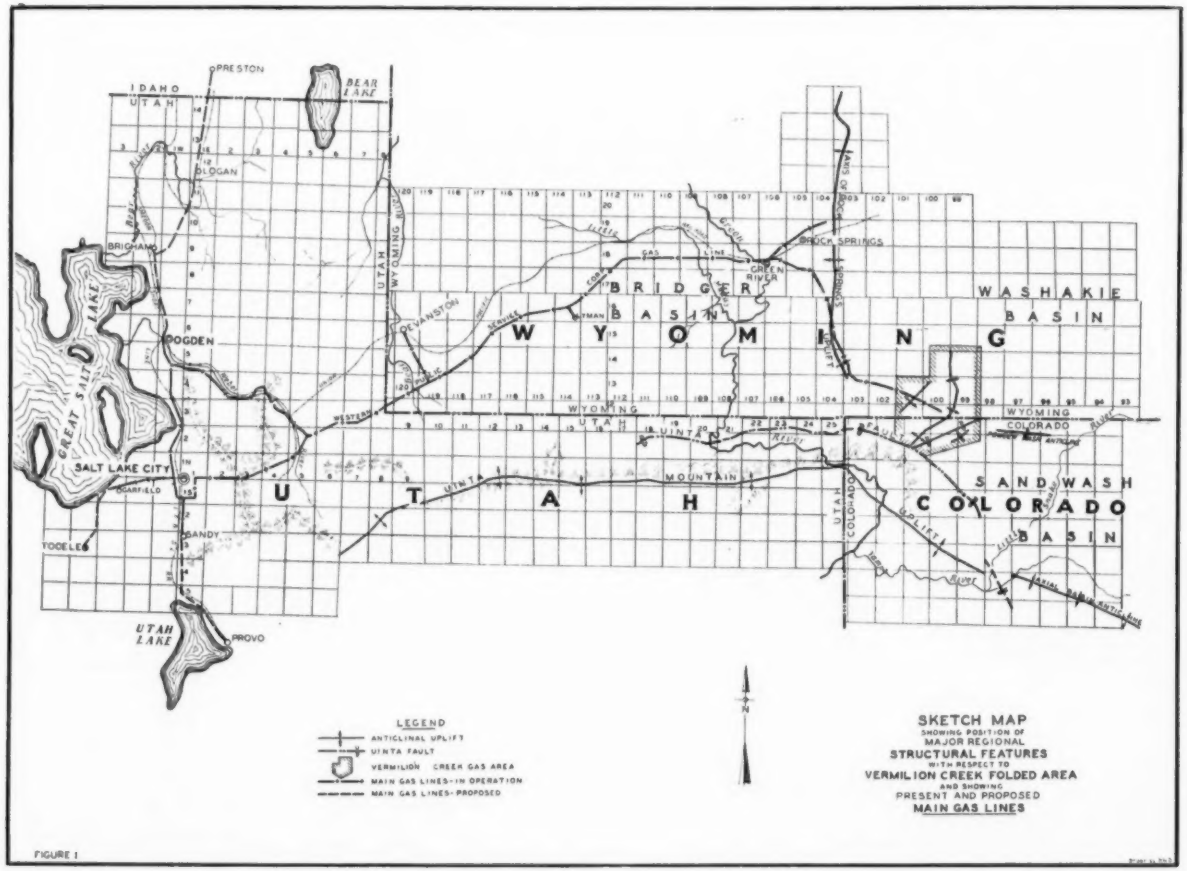
PRESTON
IDAHO
UTAH
BEAR LAKE
LOGAN
BRIGHAM
OGDEN
GREAT SALT LAKE
SALT LAKE CITY
TOOELE
SANDY
PROVO
UTAH LAKE
WYOMING
BRIDGER BASIN
WASHAKIE BASIN
GREEN RIVER
ROCK SPRINGS
KEMMERER
EVANSTON
COLORADO
UTAH
UINTA MOUNTAIN
SAND WASH BASIN
LEGEND
ANTICLINAL UPLIFT
UINTA FAULT
VERMILION CREEK GAS AREA
MAIN GAS LINES-IN OPERATION
MAIN GAS LINES-PROPOSED
N
SKETCH MAP
SHOWING POSITION OF
MAJOR REGIONAL
STRUCTURAL FEATURES
WITH RESPECT TO
VERMILION CREEK FOLDED AREA
AND SHOWING
PRESENT AND PROPOSED
MAIN GAS LINES
FIGURE 1

FIG. 1

and Utah with the south line of Wyoming, and because of this proximity, the area is commonly referred to as a part of the "Three-Corner country."

Earlier Reports and Acknowledgments

The general region of which the Vermilion Creek gas area is a comparatively small part has been of interest, geologically, since J. W. Powell's report in 1876.[1] Later reports by Clarence King,[2] C. A. White,[3] A. R. Shultz,[4] J. D. Sears,[5] and W. H. Bradley[6] indicate continued interest in the region.

The writer is indebted to W. B. Emery, geologist, and R. G. Kurtz, assistant geologist, of the Ohio Oil Company, Casper, Wyoming, who in 1928 mapped the Canyon Creek structure, thus initiating the detailed structural work in the Vermilion Creek area that was completed in 1929 by the writer and his assistants. To G. B. Gariepy and R. W. McCanne, assistant geologists, Mountain Fuel Supply Company, Rock Springs, Wyoming, who, in 1929, under the direction of the writer, did excellent work in mapping a large part of the area shown in Figure 3, grateful acknowledgment is rendered. To John McFayden, president of the Mountain Fuel Supply Company, the writer is indebted for permission to publish this paper.

Topography

The Tertiary area drained by Vermilion Creek and its tributaries consists of rolling hills deeply incised by the main streams of the drainage system. So deep, irregular, and steep is the dissection that incipient bad-lands are in the making in many places adjacent to the main drainage

[1] J. W. Powell, "Report on the Geology of the Eastern Portion of the Uinta Mountains," *U. S. Geol. and Geog. Survey Terr.*, 2nd Div. (1876).

[2] Clarence King, *U. S. Geol. Expl. 40th Par. Rept.*, Vol. 1 (1878).

[3] C. A. White, "Report on the Geology and Physiography of a Portion of Northwestern Colorado and Adjacent Parts of Utah and Wyoming," *U. S. Geol. Survey 9th Ann. Rept.* (1889).

[4] A. R. Shultz, "Oil Possibilities in and around Baxter Basin in the Rock Springs Uplift, Sweetwater County, Wyoming," *U. S. Geol. Survey Bull. 702* (1920).

[5] J. D. Sears, "Geology and Oil and Gas Prospects of Part of Moffat County, Colorado, and Southern Sweetwater County, Wyoming." *U. S. Geol. Survey Bull. 751-G*, (1924); "Relations of the Browns Park Formation and the Bishop Conglomerate, and Their Rôle in the Origin of Green and Yampa Rivers," *Bull. Geol. Soc. Amer.*, Vol. 35 (June 30, 1924).

[6] J. D. Sears and W. H. Bradley, "Relations of the Wasatch and Green River Formations in Northwestern Colorado and Southern Utah," *U. S. Geol. Survey Prof. Paper 132-F* (1924).

canyons. Elevations above sea-level range from 6,500 feet in the canyon bottoms to 7,300 feet on the high rolling hills. The average altitude in the larger part of the mapped area shown in Figure 2 is 6,900 feet above sea-level.

The larger streams of the area, Vermilion Creek and its tributaries, Shell, Talamantes, Canyon, and Alkali creeks, are permanent, although the summer water-level, except during temporary heavy rains, is very low. All of the smaller tributaries are intermittent. Vermilion Creek is a tributary of Green River.

On the east side of the Vermilion Creek gas area is a bold, westward-facing escarpment known as the Kinney Rim. Parts of the rim are more than 8,000 feet above sea-level. It has the appearance, from the gas area, of a great semi-encircling wall. On the southwest and west, Cold Spring Mountain and Diamond Peak, the latter rising to 9,925 feet in altitude, emphasize the "great wall" effect of the Kinney Rim, and define the structural limits of the Vermilion Creek gas area.

Development

The Vermilion Creek gas area includes the first important commercial gas-producing structure (Hiawatha) developed in sediments of Tertiary age in the Rocky Mountain region. Therefore, the geological conditions affecting the area are of importance in so far as they may be applicable to other Tertiary areas.

The isolated position of the Vermilion Creek area delayed its drilling for several years. Rock Springs, Wyoming, on the Union Pacific Railroad, the nearest large town, is 70 miles distant. Craig, Colorado, on the Moffat Railroad, the nearest Colorado railway point, is 127 miles away by road. The roads between the gas area and either railroad point become almost impassable under severe winter conditions and in heavy rains. Even with the discovery of gas in large amounts, the lack of a market reasonably near delayed development more than two years. In 1929, however, The Western Public Service Corporation constructed 330 miles of pipe line to deliver gas to Salt Lake City, Utah, and adjacent towns in southwest Wyoming, southeast Idaho, and Utah. This undertaking, costing approximately $20,000,000.00, with its intake terminus in the Vermilion Creek gas area, established a market for the shut-in gas, and additional drilling and development were commenced on a large scale by the Mountain Fuel Supply Company, the producing subsidiary of The Western Public Service Corporation.

To date, six closed domes have been mapped in the Vermilion Creek area (Fig. 4), namely, Hiawatha, West Hiawatha, Alkali Creek, Canyon Creek, Sugar Loaf, and Shell Creek. Of these, Hiawatha and West Hiawatha have been proved for gas production.

The discovery well in the Vermilion Creek gas area was completed by The Sormir Petroleum Company at the Hiawatha dome in February, 1927. This well, the Florence L. Wilson No. 1, was drilled to 2,220 feet, where an estimated open flow of 45,000,000 cubic feet per day and a rock pressure of 760 pounds per square inch were encountered.

The second and third productive gas wells, similar to the first, were completed at Hiawatha by The Ohio Oil Company in November, 1927, and June, 1928, respectively.

A well commenced by the Reiter-Foster Oil Company at Hiawatha was taken over and drilled to completion by the Mountain Fuel Supply Company in May, 1929. This hole, although well located structurally, found the upper gas sands barren and was drilled to 3,570 feet, where an open flow of 3,250,000 cubic feet and a rock pressure of 1,325 pounds per square inch were encountered.

The fifth and last well completed to date at the Hiawatha dome, the M. W. Newberger No. 1, was commenced by The Sormir Petroleum Company and drilled to completion by the Mountain Fuel Supply Company in September, 1929. The producing sand encountered at 2,375 feet made approximately 25,000,000 cubic feet of gas per day with a rock pressure of 925 pounds per square inch.

An important development of 1929 that has substantially increased the proved gas acreage in the Vermilion Creek gas area is The Texas Company's drilling operation, the W. C. Berlin No. 1, at West Hiawatha (Fig. 4). This well made 36,000,000 cubic feet of gas from a sand at 1,535 feet, 23,000,000 cubic feet from a sand at 2,000 feet, 3,700,000 cubic feet from a sand at 2,160 feet, and about 2,000,000 cubic feet from a sand at 2,230 feet. Thus, the total open-flow capacity of the well approximates 65,000,000 cubic feet per day from four separate sands. Rock pressures vary from 610 to 800 pounds per square inch. This is the first well drilled at West Hiawatha.

In addition to these completed gas wells, operations are in progress on the Hiawatha, West Hiawatha, Alkali Creek, Canyon Creek, and Sugar Loaf domes (Figs. 2 and 4). The results of this drilling, which is expected to be completed in 1930, should give much information as to the probable extent of the gas area.

Stratigraphy

GENERAL STATEMENT

By far the greater part of the rocks exposed in the Vermilion Creek gas area, and all of the rocks exposed on the crests of the structural domes, belong to the lower Wasatch formation of Eocene Tertiary age (Fig. 2). A few outliers and most of the rocks around the west, north, east, and southeast borders of the structural area belong to the Tipton shale of Green River age, also Eocene Tertiary, but in general somewhat younger than Wasatch. Farther out, on the east and southeast, Cathedral Bluff red beds of upper Wasatch age rise to form the Kinney Rim escarpment (Fig. 2). In the southwest part of the mapped area, rocks ranging in age from Cretaceous to Cambrian occur between the Sparks fault and Cold Spring Mountain. These older rocks, within the limits of the described area (Fig. 2), are partly covered with an unconformable mantle of Browns Park sediments, of Miocene(?) age.

The Vermilion Creek gas area terminates at the Sparks fault, which is shown on Figure 3 as extending from northwest to southeast across T. 11 N., R. 101 W., in Colorado. As all of the pre-Tertiary rocks occur southwest of the Sparks fault, outside the limits of the gas area, little space is devoted to them in this paper.

Table I, after J. D. Sears,[1] shows the succession and character of geologic formations from the Dakota sandstone of Upper Cretaceous age to the Browns Park formation of Miocene(?) age, exposed in Moffat County, Colorado, and southern Sweetwater County, Wyoming.

Table II gives the same information on geologic formations exposed within the mapped limits of the Vermilion Creek gas area.

A comparison of Table I with Table II clearly reveals that only a part of the upper stratigraphic section for southern Sweetwater County, Wyoming, and Moffat County, Colorado, is exposed within the limits of the area mapped (Fig. 2). The following discussion of formations is applicable to the formations examined, drilled, or considered of importance in a discussion of the gas area only.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

Mancos shale.—The Mancos shale includes the oldest sediments believed of importance in a discussion of the Vermilion Creek gas area.

[1] J. D. Sears, *op. cit.*

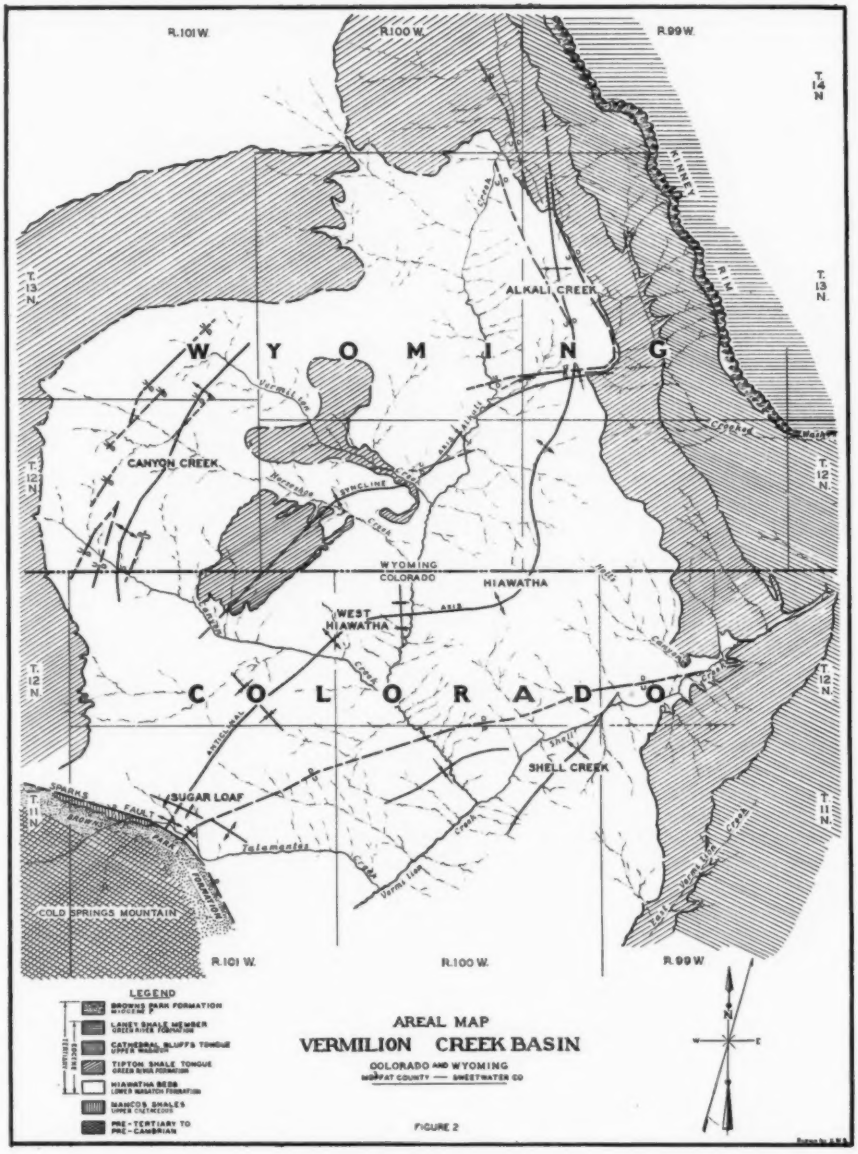
R.101 W.
R.100 W.
R.99 W.
T. 14 N.
T. 13 N.
T. 12 N.
T. 11 N.
W Y O M I N G
C O L O R A D O
ALKALI CREEK
CANYON CREEK
WYOMING
COLORADO
HIAWATHA
WEST HIAWATHA
SHELL CREEK
SUGAR LOAF
COLD SPRINGS MOUNTAIN
LEGEND
AREAL MAP
VERMILION CREEK BASIN
COLORADO AND WYOMING
FIGURE 2

FIG. 2

TABLE I

GENERAL SECTION OF GEOLOGIC FORMATIONS EXPOSED IN MOFFAT COUNTY, COLORADO AND SOUTHERN SWEETWATER COUNTY, WYOMING

SYSTEM	SERIES	GROUP AND FORMATION	THICKNESS	CHARACTER
Quaternary		Alluvium; terrace gravels		Sandy clay along streams and in valley bottoms; terrace gravel on benches along rivers.
		Unconformity		
Tertiary	Miocene (?)	Browns Park Formation / Bishop Conglomerate	Browns Park 1200 Ft. Bishop 0-200 Ft.	Browns Park is mostly soft chalk-white sandstone; beds of chert; conglomerate at base. Bishop conglomerate (basal conglomerate of Browns Park formation) consists of water-worn and subangular pebbles and boulders embedded in finer gravel and sand matrix.
		Unconformity		
	Eocene	Bridger Formation		Ash-gray and greenish clay shale; gray, buff, and blue-green sandstone; light-gray and white marl, limestone, and chert; conglomerate.
		Unconformity Locally Green River Formation (Including Laney Shale member and Tipton Tg)	1500 Ft.	Gray fissile shale and oil shale; gray clay shale; gray and buff sandstone and limestone; oölitic layers and alga reefs.
		Wasatch Formation (Including Cathedral Bluffs Tongue)	3000 Ft. 6250 Ft.*	Variegated clay shales; gray, buff and pink sandstone, grit and conglomerate; coal beds.
Tertiary (?)	Eocene (?)	Unconformity Post-"Laramie" Formation	0-800 Ft.	Gray and brown sandstone; grey and drab shale; coal beds; conglomerate at base.
		Unconformity		
Cretaceous	Upper Cretaceous	"Laramie" Formation	1020-2350 ? Ft.	Sandstone, shale and some coal.
		Lewis Shale	900-1600 Ft.	Gray marine shale and thin sandstones.
		Mesa Verde group: Williams Fork Formation	1600-2400 Ft.	Gray, white and brown sandstone; gray shale; valuable coal beds.
		Mesa Verde group: Iles Formation	1350 Ft.	Gray, white and brown sandstone predominant; gray shale, some coal beds.
		Mancos Shale	5085-5370 Ft.	Gray marine shale; thick lenticular beds of sandstone in upper 1,000 feet, and one thick sandstone near base.
		Dakota Sandstone	155-250 Ft.	Gray sandstone, at places quartzitic; gray and greenish clay shale; conglomerate of black chert pebbles.

Note: Jurassic, Triassic, Carboniferous, Devonian, Cambrian and pre-Cambrian sedimentary formations exposed by Uinta Mountain Uplift south of Vermilion Creek area. However, these earlier formations do not enter into a discussion of the gas area stratigraphy. W. T. N.

* Minimum thickness as determined in Vermilion Creek area.

5 Sears, J. D., op. cit.

TABLE II

SECTION OF GEOLOGIC FORMATIONS EXPOSED OR DRILLED IN VERMILION CREEK GAS AREA ONLY

SYSTEM	SERIES	GROUP AND FORMATION	THICKNESS	CHARACTER AND REMARKS
Tertiary	Miocene(?)	Browns Park Formation	220 1200 ? Ft.	Soft, chalk-white, quartz sandstone with lime cement. Weathers readily.
		Unconformity		
	Eocene	Bridger Formation		Completely eroded within limits of area discussed in this paper.
		Unconformity Locally		
		Green River Formation (Tipton Tongue Only Present)	367 Ft.	Light gray to gray fissle shale with a few thin bedded red to brown sandstones.
		Wasatch Formation: Cathedral Bluffs Tongue (Upper Wasatch)	1750 Ft.	Upper third or Cathedral Bluffs Tongue largely reddish colored clay shales with red to brown sandstone, frequently gritty to conglomeratic.
		Wasatch Formation: Hiawatha Member (Lower Wasatch)	4500 Ft. Total: 6250 Ft.	Lower two-thirds largely gray clay shale, gray to buff sandstones, some red clay shales, considerable coal in upper part.
		Fault Contact Only		
Cretaceous	Upper Cretaceous	Mesaverde Group: Williams Fork Formation	0 to 1000 Ft.	Gray, white and brown sandstone, gray shales, coal. Formation in part or wholly removed by Sparks Fault.
		Mesaverde Group: Iles Formation	0 to 1350 Ft.	Gray to white, soft sandstone. Remnant only exposed near Sugar Loaf Butte.
		Mancos Shale	5370 Ft.	Gray marine shale. A few thin lenticular sands in upper third. Heavy sandstone bed near base. About 94% of this formation is gray marine shale.

Its upper limit is marked by its contact with the Mesaverde formation; at its base lies the Dakota sandstone formation.

As exposed on Vermilion Creek, a short distance south of the mapped area (Fig. 4), the Mancos consists of 5,350 feet of dark gray marine shale with a minor amount of sandstone. From a study of the exposed section, it is calculated that 94 per cent of the formation may be classified as more or less impervious dark gray clay shale, and 6 per cent as sandstone, limestone, sandy concretionary beds, and carbonaceous shaly sediments. The concretionary beds are present at different places in the formation, but the principal arenaceous phase is confined to a zone of sandstones and sandy shales ranging from 160 to 300 feet above the Dakota. This zone is believed to represent the Frontier formation, which is the upper gas-bearing zone in the Baxter Basin fields 40-60 miles northwest of the Vermilion Creek gas area. A small amount of carbonaceous shale and some thin streaks of coal in this part of the observed section along Vermilion Creek further emphasize the resemblance of this zone to the Frontier as elsewhere developed in southern Wyoming. Immediately below this sandy zone and extending to the Dakota sandstone occur 150 feet of hard, platy shales with fish scales and some bentonite. This is believed to be the equivalent of the Aspen or Mowry shale formations of Wyoming.

Mesaverde group.—The Mesaverde group of northwest Colorado has been divided by E. T. Hancock[1] into two formations, namely, the Iles formation and the Williams Fork formation. In T. 10 N., R. 100 W., a short distance south of the area shown in Figures 2 and 4, the Sparks fault offsets the Williams Fork sandstone against the lower Wasatch shales. Near the Sugar Loaf butte (Fig. 4), the same fault exposes a small amount of light-colored sandstone believed to be Iles sandstone. Because of these two occurrences of the Mesaverde group, and because these sandstones may possibly be encountered by deep drilling in the Vermilion Creek gas area, a brief description of each is here given.

Iles formation (lower Mesaverde).—Immediately above the Mancos shale, on Vermilion Creek, occur 1,650-1,700 feet of massive light gray to white sandstones with a small amount of gray shale. Yellow iron stains on fracture planes and iron-like nodules occur in the light-colored sandstones which make up the bulk of this formation.

Williams Fork formation (upper Mesaverde).—Above the massive white sandstone of the Iles formation lie 550 feet of gray sandstones,

[1] E. T. Hancock, "Geology and Coal Resources of the Axial and Monument Butte Quadrangles, Moffat County, Colorado," *U. S. Geol. Survey Bull. 757* (1925).

gray shales, and thin coal beds. The sandstones of this formation are neither so massive nor so distinctively white as in the Iles formation, and the gray shales and coal streaks occupy a much larger part of the exposed thickness. Only a part of the section of the Williams Fork formation is represented on Vermilion Creek, as the Sparks fault here offsets sediments believed to be about middle Williams Fork with colored shales of lower Wasatch (Eocene) age.

TERTIARY SYSTEM

EOCENE SERIES

Wasatch formation.—The Wasatch formation of the Vermilion Creek gas area is divided into two distinct stratigraphic units, the Hiawatha member, of lower Wasatch age, and the Cathedral Bluffs red-bed tongue, of upper Wasatch age. Separating these two divisions of the Wasatch is the Tipton tongue formation, of Green River age. The Wasatch formation, which is unconformable wherever found in contact with the older rock of the region, is the gas-bearing formation of the gas area.

Hiawatha member (lower Wasatch).—In this paper the term "Hiawatha member" is assigned to the Wasatch sediments lying below the Tipton tongue formation of Green River age in the Vermilion Creek gas area. Several hundred feet of sedimentary beds assigned to the Hiawatha member have been examined along Shell Creek, immediately south of the Hiawatha dome, and on Vermilion Creek and its tributaries immediately west of the same structure. In addition, some 3,500 feet of sediments have been penetrated by holes drilled for gas. In the absence of micro-paleontological information on the lower drill cuttings, this entire drilled thickness of sedimentary rocks is believed to be lower Wasatch and is assigned to the Hiawatha member. Thus a minimum thickness in excess of 4,000 feet of beds is believed to comprise the Hiawatha member, and it is possible that the maximum thickness may be considerably greater, as the base has not yet been reached.

Inasmuch as the producing horizons of the Vermilion Creek gas area are in the Hiawatha member, these sediments are of particular interest.

In general, the beds of the Hiawatha member are of fresh-water origin, partly fluviatile and partly lacustrine. Gray clay shales constitute the predominating part of the member, although there is also a minor amount of green-to-pink shale and considerable lignite and dark carbonaceous shale, particularly in the highest 1,000 feet (Fig. 3). A few interbedded layers of gray-to-buff sandstone are important as known and possible reservoirs for gas and perhaps oil. In physical characteris-

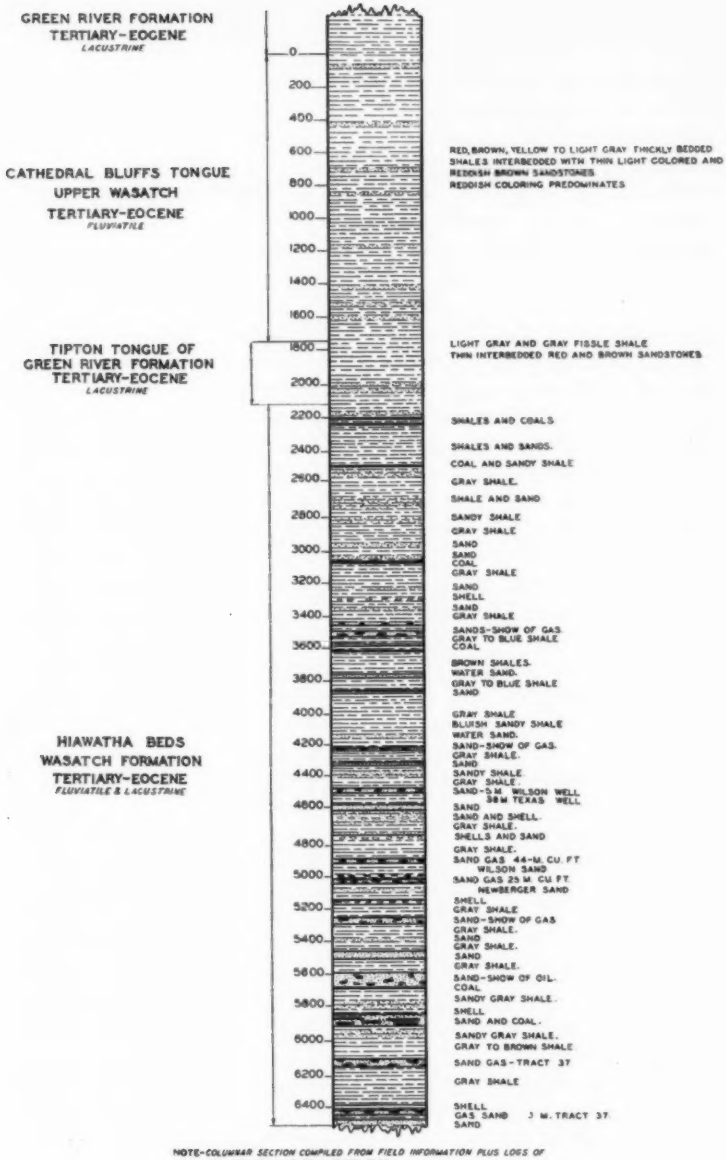

FIG. 3.—Type columnar section for Vermilion Creek basin. Depth shown in feet.

tics, they range from fine-grained and tightly cemented to coarse-grained, poorly sorted and loosely cemented sandstones, and to grits and local conglomerates. Laterally the sandstone members exhibit well developed lenticularity, thickening and thinning, from a few inches to 20 or 30 feet in a few hundred feet. Cross-bedding is marked in these thicker sand members, which yield readily to erosion. The thinner but finer-grained sandstones are more resistant and tend to form the escarpments along the drainage canyons.

Vertebrate bone fragments and invertebrate fresh-water fossil remains such as *Unio*, *Viviparus*, *Goniobasis*, and *Ostrea*, were noticed in beds of the Hiawatha member.

The gas-producing sands of the area occur in the Hiawatha member, ranging from 2,450 to 4,100 feet below the contact of that member with the overlying Tipton tongue of the Green River formation. Their pronounced lenticularity and differing degrees of porosity, as shown by drilling, resemble the outcrop characteristics observed on the surface of beds assigned to the Hiawatha member.

The producing sands range from 3 to 45 feet in thickness, as drilled. The total number of producing sands is unknown, as most of the wells produce from the first satisfactory sand encountered. However, on the Hiawatha dome at least two sands are known to be productive of "big gas," that is, more than 20,000,000 cubic feet per day, open flow, from each sand. On West Hiawatha two "big-gas" sands comparable, but not correlated, with the Hiawatha sands have been drilled, and in addition two small producing sands have been encountered by deeper drilling.

Above the Hiawatha member, but separated from it by fissile shales of the Tipton tongue of the Green River formation, lies the Cathedral Bluffs red-bed tongue.

Cathedral Bluffs tongue (*upper Wasatch*).—The Cathedral Bluffs tongue or upper Wasatch formation is excellently exposed on the east side of the Vermilion Creek area in the bluffs that form Kinney Rim. They are red, purple, brown, yellowish green to light gray thickly bedded clay shales. Interbedded with the shales are thin, gray to reddish brown sandstones. Red shales predominate throughout the 1,750 feet of sediments that comprise the Cathedral Bluffs tongue in this area.

Green River formation.—The Green River formation is represented in the area by the Tipton tongue only. Both the Tower sandstone and the Laney shale members of Shultz[1] are entirely missing.

[1] A. R. Shultz, *op. cit.*

The Tipton tongue as exposed in the gas area consists of brown to gray, locally silvery, fissile shale with a few thin, interbedded, drab to brown sandstones and some conglomerate. The formation, of fresh-water lacustrine origin, is distinctive in appearance and readily recognizable on its outcrop. In the gas area the Tipton tongue thickness was measured as 367 feet.

The occurrence of the Tipton tongue of Green River age in the Vermilion Creek gas area, lying between Cathedral Bluffs beds of upper Wasatch age and Hiawatha beds of lower Wasatch age, is due to a remarkable example of formational interfingering on a very large scale. The interfingering is caused by the Tipton tongue entering the area from the north as a separating wedge in the Wasatch formation and disappearing some distance southeast of the Vermilion Creek area. The Cathedral Bluffs tongue, entering the area from the south, disappears northward. This subject has been very ably treated by J. D. Sears and W. H. Bradley,[1] and their conclusions have been verified by the writer as a result of field work in 1928 and 1929.

Bridger formation.—Within the gas area the Bridger formation, the youngest Eocene formation represented in northwest Colorado and southwest Wyoming, is entirely missing as a result of uplift and erosion, although there is some reason to believe that this formation at one time covered part of the area.

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Browns Park formation.—The only rocks noticed as definitely belonging to the Browns Park formation within the limits of the Vermilion Creek gas area occur as an unconformable capping on Cretaceous and older rocks southwest of the Sparks fault. This capping ceases abruptly and completely northeast of the fault-plane surface trace (Fig. 2).

The Browns Park formation, originally named by Powell[2] from its type exposures in Browns Park on Green River south of Cold Spring Mountain, consists of soft, sugary, fairly well bedded sandstone with a distinctly chalk-white appearance that easily identifies the formation on good outcrops. Under the microscope the sandstone is seen to be composed of well worn quartz grains with a calcareous cement which breaks down readily. Grits and small pebble conglomerate strata were also noticed in the field, together with a minor amount of chert.

[1] J. D. Sears and W. H. Bradley, *op. cit.*

[2] J. W. Powell, *op. cit.*

SOURCE OF TERTIARY SEDIMENTS

Field evidence noted during the course of mapping indicates the Uinta Mountains on the southwest as the primary source of Tertiary sediments in the Vermilion Creek area. Powell[1] first noted the thickening of formations approaching the mountains and the lateral changes from shales to sandstones and conglomerates. Sears and Bradley[2] noted the many conglomeratic phases in the Tertiary sediments and the local interfingering near the mountains. They also identified the gray cherty limestone boulders and quartzite pebbles at the Sugar Loaf butte (Fig. 4) as being derived from the massive limestones and quartzites of Carboniferous age and older, now exposed on the flanks of the Uinta Mountains.

In the Vermilion Creek gas area, the proximity to the Uinta Mountains uplift and the similarity of rock material, where erosional changes have not completely destroyed all semblance of the older rock formations of the near-by mountains, leaves but little doubt, in the opinion of the writer, that the sediments now comprising the Tertiary beds of the Vermilion Creek drainage basin were largely derived from the Uinta Mountains.

STRUCTURE

REGIONAL STRUCTURE

The outstanding structural feature of the Vermilion gas area is the long sinuous northeast-southwest-trending anticlinal uplift on which are the Alkali Creek, Hiawatha, West Hiawatha, and Sugar Loaf domes. Flanking this major line of uplift on either side are the Canyon Creek and Shell Creek domes, the former on the northwest and the latter on the southeast (Fig. 4).

To understand the structural conditions of the Vermilion Creek region it is necessary briefly to indicate the major structural movements of northwest Colorado, southern Wyoming, and adjacent parts of Utah (Fig. 1).

Uinta uplift.—The primary structural feature of this large region is the great Uinta anticlinal upthrust. From the eastern Wasatch Mountain syncline of Utah, where the folding starts, the Uinta mountainous arch extends in a general easterly direction, parallel with, but south of, the Wyoming state line, for a distance of more than 120 miles, with an average breadth of about 40 miles. The arch then bends southeast near the Utah-Colorado state line and continues for another 60 miles

[1] J. W. Powell, *op. cit.*

[2] J. D. Sears and W. H. Bradley, *op. cit.*

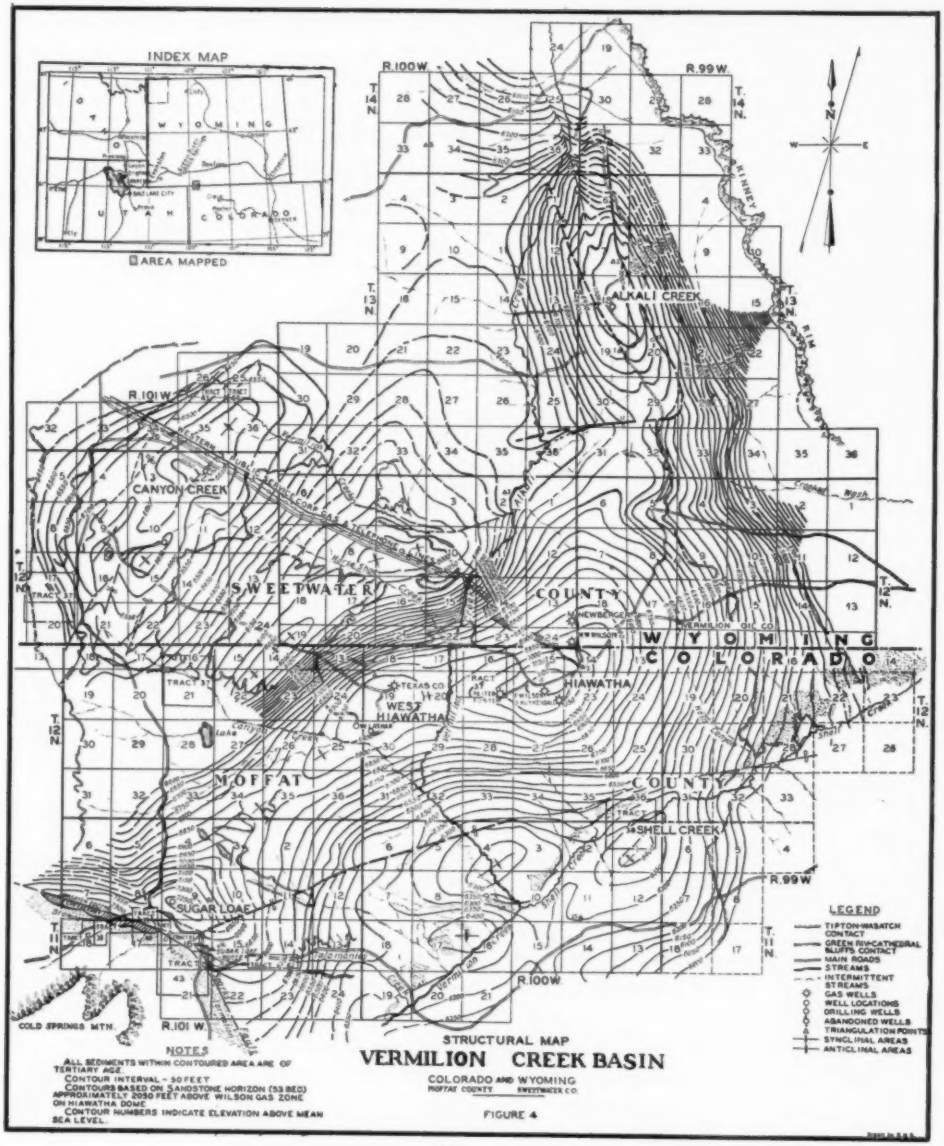
INDEX MAP
AREA MAPPED
R.100W.
R.99W.
R.101W.
T. 14 N.
T. 13 N.
T. 12 N.
T. 11 N.
ALKALI CREEK
CANYON CREEK
SWEETWATER
COUNTY
WYOMING
COLORADO
HIAWATHA
WEST HIAWATHA
MOFFAT
SHELL CREEK
SUGARLOAF
COLD SPRINGS MTN.
LEGEND
TIPTON-WASATCH CONTACT
GREEN RIVER-CATHEDRAL BLUFFS CONTACT
MAIN ROADS
STREAMS
INTERMITTENT STREAMS
GAS WELLS
WELL LOCATIONS
DRILLING WELLS
ABANDONED WELLS
TRIANGULATION POINTS
SYNCLINAL AREAS
ANTICLINAL AREAS
NOTES
ALL SEDIMENTS WITHIN CONTOURED AREA ARE OF TERTIARY AGE.
CONTOUR INTERVAL - 50 FEET
CONTOURS BASED ON SANDSTONE HORIZON (53 BED) APPROXIMATELY 2050 FEET ABOVE WILSON GAS ZONE ON HIAWATHA DOME
CONTOUR NUMBERS INDICATE ELEVATION ABOVE MEAN SEA LEVEL.
STRUCTURAL MAP
VERMILION CREEK BASIN
COLORADO AND WYOMING
MOFFAT COUNTY SWEETWATER CO.
FIGURE 4

FIG. 4

in Colorado (Fig. 1). The mountainous part of the arch ends 20 miles south of the Vermilion Creek gas area, but the anticlinal flexure continues in a general southeasterly direction in Colorado for more than 35 miles under the name of the Axial Basin anticline. Rocks of pre-Cambrian age (Uinta quartzite) form the core of the fold and extend along the mountainous axis from end to end with rocks ranging from Cambrian to Cretaceous in age forming the steep-dipping flanks on both the north and south sides. Peaks as high as 13,000 feet above sea-level occur in the central part of the Uinta uplift, making the whole a major topographic as well as structural feature. The Green River basin, the primary structural basin of southwest Wyoming, lies on the north side of the Uinta uplift.

The deformation now known as the Uinta uplift probably represents the revival, in late Cretaceous time, of folding along an ancient line of weakness and uplift. The renewed movement continued at least to Miocene(?) time, as all sedimentary formations up to and including the Browns Park formation have been affected on the flanks of the upfold.

Rock Springs uplift.—The second regional structural feature of major importance is the Rock Springs uplift. From the Red Creek syncline, which is the northern structural limit of the Uinta upfold, the Rock Springs uplift extends northward nearly at right angles to the Uinta anticlinal upfold for about 85 miles. The Rock Springs anticline brings to the surface 1,100 square miles of Upper Cretaceous rocks of the Laramie, Mesaverde, and Baxter shale formations, through the great thickness of Tertiary rocks of the Green River basin. The uplifting movement is thought to be more recent in age than the Uinta folding and is assigned to the late Tertiary.

The Rock Springs anticline divides the Green River basin into two small structural units, the Bridger basin on the west and the Washakie basin on the east (Fig. 1). On the south flank of the Washakie basin, a low northwest-southeast fold in Tertiary rocks known as the Powder Wash anticline separates the Washakie basin from the Sand Wash basin. As both the Washakie basin and the Sand Wash basin are believed tributary, in so far as gas drainage is concerned, to the Vermilion Creek gas area, they are here discussed (Fig. 1). As the Bridger basin, however, is cut off from the gas area by the Rock Springs uplift, it has no bearing in a discussion of the gas area.

Washakie and Sand Wash basins.—The Washakie structural basin occupies an area of 100 townships or more east of the Rock Springs uplift and east and northeast of the Vermilion Creek gas area (Fig. 1).

Rocks of the Bridger formation crop out in the trough of the basin with sediments belonging to the Green River and Wasatch formations forming the exposed flanks. The structural folding of the Vermilion Creek gas area is developed on the southwest rim of the Washakie basin between the north-south-trending Rock Springs uplift and the northwest-southeast phase of the Uinta Mountain uplift.

The Sand Wash structural basin, as before stated, lies immediately south of the Washakie basin and northeast of the Uinta Mountain uplift where that uplift assumes its southeast trend (Fig. 1). The Sand Wash basin is smaller than the Washakie basin in area, occupying not more than 30 townships. The low folding which separates the Washakie basin from the Sand Wash does not extend into, or cut off, the Vermilion Creek area; therefore, the Sand Wash basin, like the Washakie basin, may be considered tributary to the gas structural area for gas drainage. As in the Washakie basin, rocks of the Bridger formation occupy the trough of the Sand Wash basin with Green River, Wasatch, and Bridger beds comprising the flanks.

Vermilion Creek area folding.—In general, the main axis of folding, as well as the axes of the flanking domes, of the Vermilion Creek gas area as developed, is normal to the Uinta uplift line of folding and faulting and at an angle of 45° to the Rock Springs line of folding. It is the belief of the writer that the folding movements of the gas area were induced by a combination of the two major upfolding movements already mentioned. The inceptive movement is thought to have been induced through the Uinta Mountain uplift exerting strong lateral pressures toward the north and northeast. Subsequently, the Rock Springs uplift, exerting similar pressures toward the east, completed the structural deformation of the Vermilion Creek gas area.

FAULTING

In addition to the faulting confined to individual domes in the Vermilion Creek area and later discussed in this paper, two large faults were mapped that are sufficiently exceptional to justify special discussion.

Sparks fault.—The Sparks fault as mapped (Figs. 2 and 4) is believed to be a continuation of the great Uinta fault described by J. W. Powell in 1876.[1] Although a heavy covering of detrital rock in T. 11 N., R. 102 W. obscures several miles of the surface trace, the fault relationship with the adjacent rocks and the displacement and consistent alignment of the fault plane on both sides of the covered area leaves little doubt, in the

[1] J. W. Powell, *op. cit.*

opinion of the writer, that the Sparks fault is a continuation of the Uinta fault zone. The Uinta fault zone is known to extend at least 60 miles west of the Vermilion Creek area and, if correlated with the Sparks fault, would have a total length of not less than 70 miles. Powell estimated the displacement on the Uinta fault at 23,000 feet, and Shultz,[1] in a more recent work, estimated it as not less than 20,000 feet. However, the Sparks fault extension is believed to have a total displacement of not more than 10,000 feet and possibly less than 7,000 feet. This decrease in displacement occurs as the fault approaches its eastward termination.

In the Vermilion Creek area the Sparks fault offsets Mancos shale of Upper Cretaceous age against Hiawatha beds of Eocene age. The normal stratigraphic interval between these two sedimentary horizons is approximately 10,000 feet (Table I). However, this is believed to be much greater than the actual displacement. The following discussion treats briefly some of the field evidence pertinent to this question.

On the east flank of the Rock Springs uplift, 30 miles north of the Vermilion Creek area, lower Wasatch beds lie unconformably on beds identified as Laramie (youngest Cretaceous). On the southeast flank of the Rock Springs uplift, 12 miles north of the Vermilion Creek area, Wasatch beds lie unconformably on gray marine shales identified as Lewis shales (pre-Laramie). Approximately 20 miles east of the Vermilion Creek area Wasatch beds lie unconformably on Mesaverde sandstones (pre-Lewis). Along the course of the Sparks fault, lower Mesaverde sandstone and Mancos shales offset lower Wasatch beds. The progressively older beds in contact with the Wasatch, approaching the east end of the Uinta Mountains, suggest that in the Vermilion Creek area Mesaverde beds of Upper Cretaceous age may be directly subjacent to the Wasatch sediments. Definite proof of this will be lacking until the examination of cuttings from drilling operations definitely determines the lower Wasatch contact and the identity of the subjacent rocks.

Information on the identity of the rocks below basal Tertiary is required to determine, with any degree of accuracy, the amount of vertical displacement represented by the Sparks fault. As before stated, should the Wasatch formation be underlain by Laramie beds, as in a full normal section, the amount of displacement may exceed 10,000 feet. Should upper Mesaverde beds underlie the Wasatch, the Sparks fault displacement may be less than 7,000 feet.

The Sparks fault is evidently a normal fault, with its downthrow on the north side and with an almost vertical plane. Contemporaneous in age

[1] A. R. Shultz, *op. cit.*

with the Uinta uplift, the faulting movement seems to have continued into, and possibly through, Browns Park time (Miocene?). The abrupt cessation of Browns Park sedimentation at the Sparks fault (Fig. 2), and its complete absence in the Vermilion Creek folded area on the northeast indicate movement after part of the Browns Park formation was deposited.

Shell Creek fault.—The Shell Creek fault was first noticed on the north side of Shell Creek (Figs. 2 and 4), in the drainage canyons tributary to that stream. Where first measured, the fault appeared to be normal, with a displacement of approximately 100 feet with the downthrow on the north side (Fig. 4). From this point in Sec. 29, T. 12 N., R. 100 W., Colorado, the fault line was traced southwest for 12 miles, where it seemed to branch off the Sparks fault in Sec. 16, T. 11 N., R. 101 W., Colorado. Extending southwestward from the location where first measured, the Shell Creek fault decreased in amount of displacement to Sec. 11, T. 11 N., R. 101 W., Colorado, where an abrupt reversal dropped the south side 100 feet, forming a scissors fault (Fig. 4). From the point of reversal the displacement increased toward the Sparks fault so that at the main fault the "scissors" displacement is approximately 300 feet.

In passing immediately north of the Sugar Loaf conglomeratic butte this fault has dropped the south end of the Sugar Loaf dome, and with it the conglomeratic capped butte, approximately 200 feet (Fig. 4).

Hiawatha Dome

The Hiawatha dome, the main gas-producing structure in the Vermilion Creek gas area, is a practically unfaulted, quaquaversal structure on the major line of folding of the Vermilion Creek area. Such faulting as was observed in connection with the mapping of the Hiawatha dome is confined to the synclines on the north and south sides of the dome (Fig. 4). The dome has a definite structural closure of 235 feet and the area so enclosed is approximately 4,400 acres. Of this area about 3,700 acres are located in the state of Colorado and about 700 acres in the state of Wyoming.

Although only 235 feet of closure was mapped on the Hiawatha dome as an independent structural unit in the Vermilion Creek area, it is probable that 600 feet, or possibly more, closure is developed on the major line of folding of which the Hiawatha dome is a part (Fig. 4). This line of anticlinal folding (Figs. 2 and 4) extends in a general northeast direction away from the Sparks fault to the west flank of the Hia-

watha dome. From there it bends eastward to the apex of the dome, where it swings sharply northward and continues on that course to its extremity north of the Alkali Creek faulted dome.

The crest of the Hiawatha dome is in Sec. 22, T. 12 N., R. 100 W., Colorado. Both the Florence L. Wilson No. 1, the discovery gas well, and the Georgia Kuykendall No. 1, the second gas well drilled, are in Section 22. Both wells are within 60 feet, structurally, of the crest of the dome. The Meyer W. Newberger No. 1, in Sec. 13, T. 12 N., R. 100 W., Wyoming, the latest producing gas well drilled at the Hiawatha, is structurally 185 feet down the north flank of the dome (Fig. 4).

West Hiawatha Dome

A second closed area smaller in extent and with a much smaller amount of closure than the main dome, occurs about 125 feet structurally down the west flank of the Hiawatha dome (Fig. 4). This dome, known as West Hiawatha, is on the same main line of anticlinal folding as is the Hiawatha dome. West Hiawatha has 57 feet of structural closure with a definitely closed area of 885 acres. As on the Hiawatha dome, the amount of closure developed at West Hiawatha as an independent structural unit is only a small part of the total amount of closure developed on the major line of folding, and the productive area may be expected to extend beyond the limits of the local closure.

Although Hiawatha and West Hiawatha are separate domes, both are included in the same general outside closing contour (Fig. 4). Furthermore, so shallow is the intervening syncline that considerable reason exists for believing gas-reservoir conditions may continue through the shallow syncline, making Hiawatha and West Hiawatha a single gas pool.

The structural crest of West Hiawatha is in Sec. 19, T. 12 N., R. 100 W., Colorado, and all of the area within the mapped closure is also in Colorado. The Texas Company's drilling well, the W. C. Berlin No. 1, previously mentioned, has already developed a total of 65,000,000 cubic feet of gas per day from four sands between 1,535 and 2,245 feet in depth.

Alkali Creek Faulted Dome

The Alkali Creek dome is the most northerly of the closed domes on the Vermilion Creek major line of folding (Fig. 4). Faulting on a very considerable scale has affected both the extent and the shape of the Alkali Creek dome and may have seriously interfered with its gas possibilities because the producing horizons as found at Hiawatha are so displaced

by fault movement at the Alkali Creek dome that the normal basinward drainage area on the east is, in effect, cut off from the dome. With the several water-bearing sands and the thicker impervious gray shale as revealed in the drilling at the Hiawatha dome, it would be hazardous to expect any fault displacement to bring into juxtaposition gas sands on both sides of a fault plane in this area.

The fault of greatest displacement on the Alkali Creek dome is immediately east of the axis of folding. Passing through the northeast corner of Sec. 18, T. 13 N., R. 99 W., this fault, with a displacement of 775 feet, immediately east of the Alkali structural "high," trends parallel with the anticlinal axis on a course about N. 10° W. From the same section corner the fault extends southeast about S. 25° E., still paralleling the line of folding. One-half mile north of the southwest corner of Sec. 28, T. 13 N., R. 99 W., the fault turns sharply west, crosses the axis of folding in the shallow syncline between the Hiawatha and Alkali Creek domes and continues S. 5° W. for more than 3 miles. At the sharp westerly bend (Fig. 4) the displacement has decreased from 775 feet to 450 feet and 3 miles west of the bend no displacement is visible. This fault, with its upthrown side on the west and north of the plane of displacement, causes the larger part of the highest structural area of the Alkali Creek dome to be within the limits of an upthrown wedge-shaped fault block (Fig. 4).

Two other faults also occur on the Alkali Creek dome north and west of the previously described displacement. The more westerly of these extends almost across the dome in a course approximately parallel with the axis of folding. However, there is little displacement, less than 40 feet wherever noticed, and the break must be considered an incipient fault showing considerable drag in the beds, but very little breaking. Such displacement as was noticed is down on the east side.

The second of the two smaller faults on the dome lies between the large fault first described and the small westerly fault (Fig. 4). It attains a maximum displacement of 150 feet in Sec. 36, T. 14 N., R. 99 W., but decreases in magnitude within a short distance of the crest of the dome. Like the two faults before described, the downthrown side is toward the east.

The amount of closure on the Alkali Creek dome is entirely dependent upon the faulting and is probably between 200 and 500 feet.

Sugar Loaf Area

The Sugar Loaf structural area represents the combination of a small closed dome and fault structure. The domed area is the fourth of

the independently closed structures on the main line of folding of the Vermilion Creek gas area. The dome is comparatively small, with not more than 320 acres within the 65 feet of folded closure. However, the Sparks fault with its great displacement is believed to give not less than 370 feet of closure to the dome and to increase its area greatly. The dome at the Sugar Loaf butte is the result of a comparatively small transverse fold, parallel with the Sparks fault, and probably induced by that faulting movement, intercepting the main Vermilion Creek line of anticlinal folding (Figs. 2 and 4).

One and one-half miles east of the domed area at Sugar Loaf, there is a second structural "high" adjacent to the Sparks fault and dependent on the fault displacement for its closure. It is 50 feet higher structurally than the dome, and may have the same closing contour, in which event the fault "high" may have more than 400 feet of total closure. This point is uncertain because much of the west side of the structural area is completely obscured by surface wash and detritus.

As pointed out previously under the heading "Faulting," the Sparks fault, which is assumed to provide some closure in the Sugar Loaf butte structural area, offsets the lower Wasatch, or Hiawatha beds, with Mancos shales. The displacement required to effect this offsetting is also discussed under "Faulting." The sedimentary relations that exist as a result of the Sparks fault displacement are particularly interesting. From an examination of the Mancos shale outcrops immediately south of the fault near the Sugar Loaf butte it seems that the highest Mancos shale only is represented (Fig. 2). On Vermilion Creek, 9 miles southeast of the Sugar Loaf butte, the measured section of Mancos shale shows 5,370 feet of sediments, of which 94 per cent may be classified as impervious dark gray shale and 6 per cent as sand, very sandy shales, and concretionary horizons. With this thick marine shale series offsetting the interbedded sandstones and shales of the Hiawatha Wasatch beds, it is the opinion of the writer that reasonably good conditions for satisfactory sealing of the gas-producing sandstones occur.

Drilling operations contemplated in the Sugar Loaf area will determine whether or not accumulation occurs on the downthrown side of the Sparks fault.

Canyon Creek Dome

The Canyon Creek dome is northwest of the main axis of folding in the Vermilion Creek basin. The Canyon Creek axis of folding also extends northeast-southwest and, in general, parallels the main struc-

tural axis of the gas area on its course between the West Hiawatha dome and the Sugar Loaf butte (Figs. 2 and 4).

The Canyon Creek dome is cut by a series of faults generally paralleling the axis of folding. Seven such faults have been mapped, each with its downthrown side toward the axis of the fold. It has been suggested[1] that the exceptional surface structure at Canyon Creek may be the reflection of pre-Tertiary structure and topography, that is, a result of settling of the comparatively soft Tertiary beds over buried escarpments possibly encircling a pre-Tertiary structural basin. Domed structures with the crests forming eroded drainage basins, the whole rimmed with steep escarpments, are typical of the Upper Cretaceous gas- and oil-producing structural areas of Wyoming, and it is possible that a similar situation may exist below the Tertiary sediments at Canyon Creek.

Although this explanation may account for some of the seeming settling and faulting on top of the Canyon Creek dome, the major dome features are obviously the result of true folding. A total of 250 feet of structural closure was mapped at Canyon Creek, including an area of eighteen sections.

Shell Creek Dome

The Shell Creek dome is on the southeast flank of the main Vermilion Creek line of anticlinal folding. The Shell Creek folding is very gentle, with controlling dips ranging from 1° to 2°. Through the northwest flank of the dome Shell Creek cuts a deep canyon more than ¾ mile wide, its bottom covered with thick alluvial fill, obscuring the structural geology on the north and northwest sides of the dome. Approximately 60 feet of closure was mapped on the Shell Creek dome and its structural position determined as 700 feet lower than the crest of the Hiawatha dome (Fig. 4).

Well Sections

Figure 5 shows the plotted logs of wells drilled and drilling at Hiawatha and West Hiawatha, together with sand correlations, so far as they can be made at present. The correlations reveal the irregular and abruptly lenticular producing sand conditions typical of the lower Wasatch formations in the Vermilion Creek area.

It is evident that irregularities in sand-body characteristics become more pronounced toward the western or southwestern part of the gas area. Inasmuch as this is also approaching the Uinta Mountains, the

[1] W. B. Emery, personal communication.

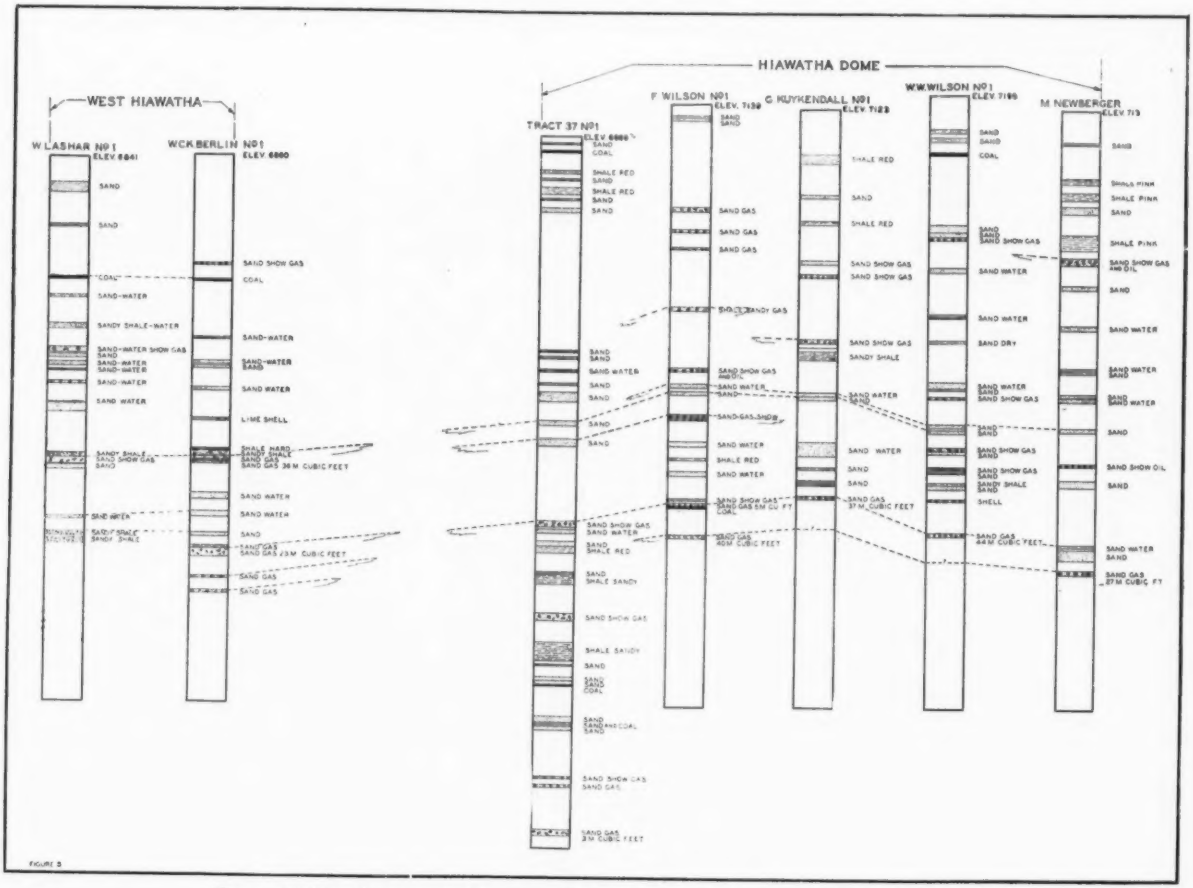

FIG. 5.—Well sections compiled from logs of drilled wells. 1 inch = approximately 865 feet.

source of much of the Tertiary sediment and, in the area where the flood-plain type of sedimentation probably occurred, extreme variations in sand-body forms may reasonably be expected.

GAS

ORIGIN

Two hypotheses are offered for the probable origin of the large quantities of natural gas already proved at the Hiawatha and West Hiawatha domes: (1) that the gas originated in the fresh-water Tertiary clay shales associated with the present producing sands in the Vermilion Creek area and in the immense structural basin tributary, for gas drainage purposes to the gas-producing domes; (2) that the gas originated in the Cretaceous formations probably subjacent to the Tertiary sediments of the Vermilion Creek gas area and has migrated upward either along fault fissures or across the beds intervening between the source rocks and the present reservoir rocks.

Drilling indicates that the producing gas horizons are not at the base of the Wasatch formation, as was originally assumed. At Hiawatha at least 1,100 feet of fresh-water sediments, predominantly clay shale, lie between the present "big-gas" horizon and any possible Cretaceous rocks. It is difficult to conceive of gas migration from any older rocks through 1,100 feet of sediments, largely impervious, into the present reservoir sandstones. Furthermore, in drilling wells, water sands are found to intervene between producing gas sands. A more plausible explanation, if the gas originated in subjacent Cretaceous marine sediments, is to assume migration upward into the present Tertiary reservoir sands along fault fracture zones. The two faults discussed under "Faulting" might possibly provide suitable channels for upward gas migration.

The fresh-water Tertiary beds in which gas production is secured at the Hiawatha and West Hiawatha domes are comparatively barren of organic remains likely to be considered suitable for the formation of a hydrocarbon such as natural gas. Conditions of deposition, fluviatile and lacustrine, of the Wasatch formation, were not favorable to the vast amount of organic life commonly thought essential for hydrocarbon generation. Yet it is in porous, lenticular sandstones associated with comparatively barren gray, and in places colored, clay shales of lower Wasatch age that the large gas wells of the Vermilion Creek gas area are developed.

To date the preponderance of evidence indicates the lower Wasatch (Hiawatha) shales as the source rocks of the natural gas. Additional drilling may reveal evidence to support fault migration from older rocks.

ACCUMULATION

Accumulation of gas in the Vermilion Creek gas area is evidently controlled by anticlinal structure. Drilling indicates that the main line of folding, including the Hiawatha, West Hiawatha, Sugar Loaf, and Alkali Creek domes, may contain most, if not all, of the commercial natural gas of the area. Within the area enveloped by structural closure on the main line of anticlinal folding, dry holes may be encountered because of local lenticularities, variable porosities, and, as at Alkali Creek dome, because of faulting.

The relation of structure and accumulation to water will not be well understood until additional contemplated drilling is completed. Present information indicates a very erratic water table, possibly due to the irregular physical characteristics of the fresh-water sand bodies.

ANALYSIS

The gas developed at the Hiawatha and West Hiawatha domes is of a very good quality. An average analysis is as follows.

	Per Cent
CH_4	96.4
C_2H_6	2.6
N_2	1.0
	100.0

Specific gravity, 0.608.
B. T. U. value, 1,017 per cubic foot.

Although this represents a fair average analysis of the gas now being produced in the Vermilion Creek area, there are slight differences in chemical analyses, observed specific gravities, B. T. U. values, and rock pressures of gases from different sands. As additional gas wells are drilled, these differences may assist greatly in correlating sand bodies.

CONCLUSION

The Vermilion Creek gas area is in the very early stage of a development program carefully planned to exhaust the gas sands through a period of years. Wide variations in physical characteristics, size and shape of reservoir sands, and the extent and effect of water-table irregularities on producing sands, make the development problems particularly intricate and interesting.

Briefly, the Vermilion Creek gas area is producing commercial gas from irregular and lenticular fresh-water sands of lower Tertiary age, and is the first important gas area developed in sediments of this age in the Rocky Mountain region. The gas accumulation is controlled by the folding of the sedimentary beds into closed structures. In at least one dome, Alkali Creek, faulting on the basinward side may have seriously interfered with accumulation; in another, the Sugar Loaf dome, faulting on the mountainward side may have increased the total amount of closure. Additional drilling, probably more than would be required in a gas area producing from a sheet sand, will be necessary to develop fully the potential gas area. The origin of the gas is not definitely known. Most of the evidence indicates that the gas originates in Tertiary shales adjacent to the reservoir sandstones; however, it is possible that the gas migrates from older underlying formations.

CONTRIBUTION TO SALT-DOME PROBLEM[1]

F. M. VAN TUYL[2]
Golden, Colorado

ABSTRACT

The results of earlier tests of the plasticity of halite are summarized. Recent determinations of the flowage pressure of rock salt at various temperatures ranging from 20° to 155° C. with an apparatus of improved design indicate a marked influence of temperature upon the plasticity of this material. The results are favorable to the opinion that deep burial, as well as deformation, may be sufficient to cause the upward movement of salt masses along lines of weakness.

INTRODUCTION

One of the many problems in the study of salt domes concerns the origin of salt masses. Although a review of the status of the several theories on the subject is not necessary, it may be stated that the intrusive theory so ably advocated by DeGolyer and others is now widely accepted. Briefly, this theory is based, in part, on the observation that some bodies of rock salt pierce sedimentary formations almost in the same way as does an igneous stock, and, in part, upon the experimental evidence that rock salt yields by plastic flow at high temperatures or pressures.

The most interesting experiments on this problem are those of Kick, Rinne, Adams, and Milch. The first three men experimented at room temperatures, using cleavage pieces of rock salt in copper cylinders sealed with paraffine, alum, or other plastic or semi-plastic substance. The application of pressure at the ends of such a cylinder caused a bulging of the walls, both the rock salt and the matrix yielding by flowage. Rinne[3] used pressures of 30,000-43,000 kilograms over an area of 15 square centimeters (28,452-40,786 pounds per square inch) for periods of 8-25 minutes; Adams,[4] after making two transfers of the flattened crystal to larger tubes, finally attained pressures as great as 157,000

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, March 20, 1930.

[2]Professor and head of the department of geology, Colorado School of Mines.

[3]F. Rinne, "Plastische Umformung von Steinsalz und Sylvin unter allseitigem Druck," *Neues Jahrb. für Min.*, 1 (1904), p. 114.

[4]Frank D. Adams, "An Experimental Investigation into the Action of Differential Pressure on Certain Minerals and Rocks, Employing the Process Suggested by Professor Kick," *Jour. Geol.*, Vol. 18 (1910), p. 489.

pounds (area not specified). In every experiment the salt was greatly deformed by plastic flow without much fracturing. In some experiments the transparency was not destroyed.

Milch's[1] tests were made at ordinary pressures and increased temperatures. He found that thin cleavage pieces of rock salt heated in an alcohol flame could be bent like beeswax. In a similar experiment, after heating long cleavage pieces in an oven for 20 minutes at a temperature of 205° C., he was able to bend them easily. These results are especially noteworthy inasmuch as the melting point of rock salt is approximately 800° C.

In reviewing the literature on the properties of rock salt, the writer was impressed with the need for more exact experiments by which the flowage pressures not only of rock salt, but also of other sediments, might be measured at different temperatures, and the results compared. Manifestly definite quantitative determinations of this nature may be employed to better advantage than qualitative data in interpreting the conditions of origin of salt-core structures. After several preliminary tests improvements in design were made and the apparatus here described was proved satisfactory.[2]

DESCRIPTION OF FLOWAGE APPARATUS AND ITS OPERATION

The flowage apparatus (Fig. 1) consists of a cylinder of cold rolled shafting steel 3¼ inches in diameter and 3⅛ inches long, having a ⅞-inch bore fitted at one end with a screw plug and at the other end with a plunger of tool steel. A collar of shafting steel with an opening large enough to accommodate the head of the screw plug serves as a base. An opening 0.067-inch in diameter in the wall of the cylinder accommodates a steel wire which is important in the flowage tests.

The procedure in the measurement of the flowage pressure of rock salt at room temperature is as follows. A cylinder of rock salt is ground so that it fits closely the bore of the cylinder. Pressures considerably greater than those necessary to produce flowage are applied through a period of several hours in order to cause a readjustment of the specimen to the apparatus. The opening in the wall of the steel cylinder is then carried through the salt cylinder, a steel wire of the same diameter is inserted, and the pressure raised in an Olsen testing machine by increments of 200 pounds every 2 minutes to the point where flowage begins.

[1] L. Milch, "Über Zunahme der Plästizitat bei Kristallen durch Erhöhung der Temperatur," *Neues. Jahrb. für Min.* 1 (1909), p. 60.

[2] The writer is indebted to Arthur L. Rae for his valuable coöperation in the design and preparation of this apparatus.

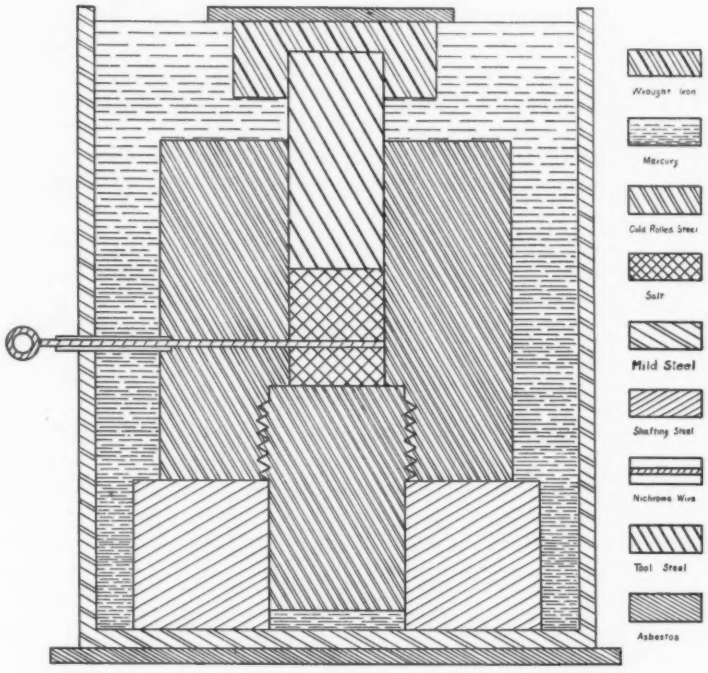

FIG. 1.—Cross section of assembled apparatus for measuring rock-flowage pressure.

Flowage is first indicated by a binding of the wire in the salt, as the diameter of the opening is reduced in size. The pressure is then lowered approximately 2,000 pounds, the hole is re-bored, and the pressure raised more slowly until the salt flowage is exactly sufficient to produce a noticeable binding of the wire during a period of 10 minutes. The flowage pressure is then checked once or twice in the same way, and the recorded pressure on the testing machine noted. The average value is accepted as the flowage pressure.

In order that flowage pressures at elevated temperatures may be measured, the apparatus is placed in a mercury bath in a steel container of the same height as the flowage apparatus, the steel wire being inserted through a small metal tube connecting the steel cylinder with the exterior of the mercury container. Heat is applied with a gasoline blow

torch, and the temperature is measured by means of a thermometer inserted in the mercury. Because of the relatively poor conductivity of rock salt, the apparatus is allowed to stand at least 3 hours at each new temperature, before the flowage tests are made. The apparatus is insulated from the testing machine by asbestos pads. The determination of the flowage pressure at each temperature is accomplished in the same way as at room temperature, several check readings being made, and the average value determined.

After the completion of the tests of a sample of rock salt, the specimen is recovered intact for study, by removing the screw plug at the base of the steel cylinder and forcing the salt downward into the opening in the collar of shafting steel by means of a steel bar of the same diameter as the plunger.

RESULTS OF TESTS ON PARADOX VALLEY SALT

Experimental work has been confined chiefly to a study of core samples of rock salt taken from a well drilled by the General Petroleum Company on the Paradox Valley anticline in southwestern Colorado. In this well, rock salt was encountered at a depth of approximately 1,300 feet. Below this depth, salt with thin streaks of shale was encountered to a depth of 6,300 feet, where the well was abandoned. The evidence that this is a salt-core structure is convincing.

The results of the flowage tests on this salt at several temperatures are presented.

Temperature in Degrees Centigrade	*Flowage Pressure in Pounds per Square Inch*
20	29,000
65	21,000
90	17,000
105	14,600
155	11,000

Figure 2 shows graphically the relation of flowage pressure to temperature. The curve falls somewhat uniformly to the vicinity of the 105° reading, where it flattens perceptibly. Inasmuch as the melting point of *NaCl* is approximately 800° C., the curve must descend very gradually at temperatures between 155° C. and the melting point.

Although the moisture content of the salt was originally 0.134 per cent, this had been reduced to 0.115 per cent after the high temperature tests were completed.

In order to determine the importance of the time element, several tests were made at 20° C. and 90° C. during longer periods of time. At

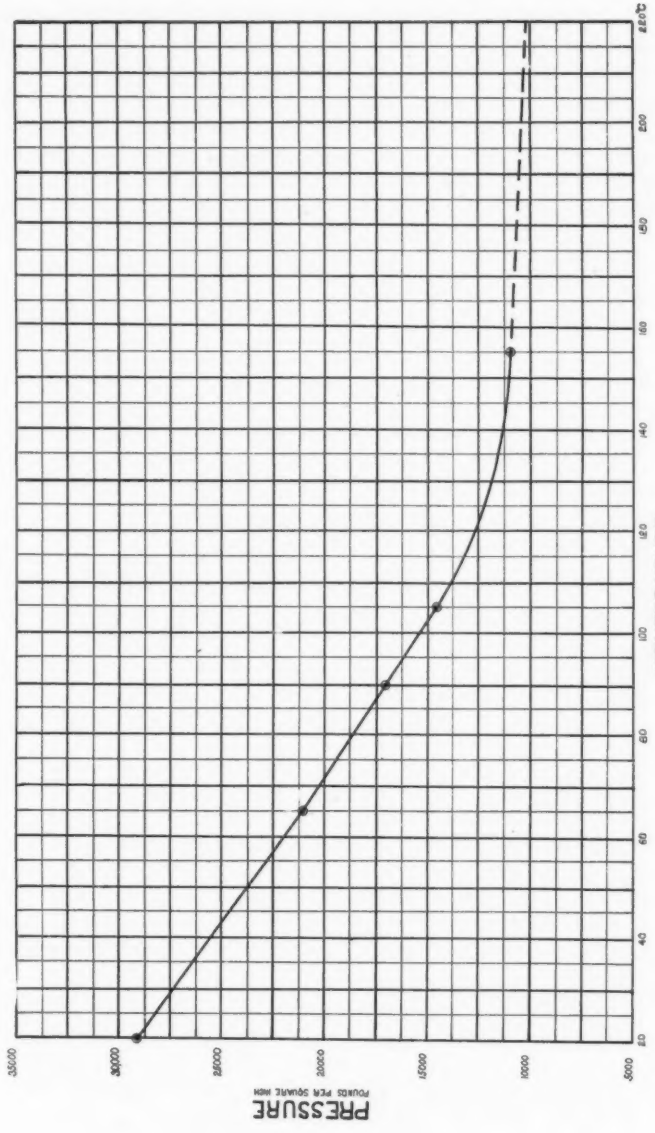

FIG. 2.—Flowage curve for Paradox Valley rock salt.

the lower temperature a pressure of 16,500 pounds per square inch caused no measurable reduction in the diameter of the opening in the salt during a period of 50 hours. After a period of 65 hours at a pressure of 20,000 pounds per square inch, there was a slight binding of the wire comparable with that obtained during a period of 10 minutes at a pressure of 29,000 pounds. At 20,800 pounds during a period of 48 hours, the evidence of flowage was much more pronounced. At a temperature of 90° C. the short-time flowage pressure proved to be 17,000 pounds per square inch, and during a period of 3 hours the salt yielded slightly at a pressure of 14,166 pounds. During longer periods of time the flowage pressure would undoubtedly be measurably lower than this amount. These long-time tests are very interesting in that the results indicate a much flatter curve than that based on the short-time tests.

Preliminary flowage tests at a temperature of 20° C. indicate that gypsum, anhydrite, and compacted shales have higher flowage pressures than rock salt. The writer assumes that the effect of higher temperatures on the flowage pressures of these substances would not be so marked as the effect on salt.

INTERPRETATION OF RESULTS

The results obtained show that high temperatures and pressures caused by deep burial, as well as the high temperatures and pressures accompanying deformation of sedimentary deposits, are sufficient to cause a plastic flow of rock salt upward in lines of weakness in the overlying strata. If one assumes an increase in pressure with depth amounting to 1 pound per square inch for each added foot of depth and a normal increase of temperature of 1° C. for each increase of 100 feet in depth, and makes allowance for the importance of the time element in the process, it seems certain that the burial of a salt mass to a depth of 12,000 feet should be sufficient to cause an upward movement of salt in any fissure which might develop in the overlying strata. However, in estimates of this kind the effect of friction and the effect of the weight of the overlying column of salt must be considered.

The lubricating effect of waters circulating about the borders of the salt cores may be more important in the phenomenon than is generally supposed.

DISCUSSION

W. Armstrong Price, Houston, Texas: Although this paper shows the possibility of salt flowage at temperatures which may reasonably have existed at the depths through which the salt cores of salt domes have moved, the ex-

perimental work of Link[1] shows the probability that such flowing salt, if highly mobile, might ascend diagonally upward along fault planes extending from the salt core. However, the fact that such tongues have *not* been found on Gulf Coast salt domes, or have not been found prominently developed, leads to the further deduction that the salt, although it was flowing under pressure, maintained essential rigidity as a unit. In other words, though flowing, the salt core maintained a high degree of cohesion, thus acting as a solid or as a stiffly viscous mass. Such apophyses of the salt cores as are described in Gulf Coast salt-dome literature seem to be short, stubby masses having broad bases. The very thin streaks of salt reported close to salt domes may be flowage apophyses. However, these latter occurrences may be caused merely by spiral wandering of well holes into and away from the edge of the main salt core.

[1]T. A. Link, "Experiments Relating to Salt-Dome Structures," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), pp. 483-508.

USE OF AIRPLANE PHOTOGRAPHS IN GEOLOGIC MAPPING[1]

WALTER A. ENGLISH[2]
Los Angeles, California

ABSTRACT

The demand for airplane photographs during the World War caused a rapid development in equipment and methods. This demand and the improvements in airplane performance laid the foundation for the present commercial applications of airplane photography. Many oil companies now use photographs in field mapping and find several peculiar features of the photographs of particular value in geologic mapping. Mosaics of various types are used for compilation of data, but line maps and contour maps can be constructed from photographs if maps of a greater degree of accuracy are desired.

The development of airplane photography beyond an experimental stage was naturally dependent on the possibility of satisfactory airplane performance. The World War, which greatly stimulated airplane development, caused a large demand for airplane photographs. Therefore, most of the methods and equipment now in use originated during the World War, when there was a rapid development in airplane photography. Inasmuch as most of the books concerning airplane photography are based on war experience, the methods outlined are those which were intended to fulfill the requirements of the intelligence service of the several armies and navies.

Although modifications in equipment and methods, as required for commercial development during peace, have been made, little has been written regarding such changes. In general, it seems that the firms engaged in commercial airplane photography attempt to keep their methods and equipment a trade secret.

Airplane photographs are classified, commercially, as verticals and obliques. Verticals are taken with the axis of the lens as nearly vertical as possible at the time of exposure. These pictures are used for various mapping purposes, including use by geologists. Obliques are ordinarily of a pictorial nature and are used as illustrations in books, advertising matter, and newspapers. Of the two types of airplane photographs, obliques are more easily interpreted by the average person who is unfamiliar with

[1]Read before the Association at the New Orleans meeting, March 21, 1930.

[2]Continental Air Map Company, 114 South Beaudry Street.

the appearance of the earth's surface as seen from directly above. In some areas, particularly of low dip, geologists have found obliques to be of value.

Most of the cameras now used commercially for vertical mapping are of the fixed-focus type, and take pictures 18 × 24 centimeters in size, or approximately 7¼ × 9½ inches. Film for use in these cameras is rolled in lengths of 75 feet and is sufficient for 100-110 exposures, according to the type of camera. The focal length of lenses used varies from 8 to 12 inches. Other things being equal, a better picture can be taken with a 12-inch lens than with an 8-inch lens, because less covering power is required. The same fact stated in terms of angle of view is that it is necessary to use a wide-angle lens of 8-inch focal length in order to get a satisfactory picture on the whole of a 7 × 9-inch exposure. The shorter focal lengths are necessary in order that the photographs may be of the required scale, without necessitating an inconveniently great altitude of flight. For a scale of 1,000 feet per inch a 12-inch lens should be used at an airplane height of 12,000 feet above the ground; a 10-inch lens at only 10,000 feet; and an 8-inch lens at 8,000 feet. A scale of 1,500 feet per inch requires an elevation of 18,000 feet above the ground and the use of a 12-inch lens, 15,000 feet and a 10-inch lens, or 12,000 feet and an 8-inch lens. Modern commercial airplanes, with motors of 125 horse power (maximum), generally have a service ceiling at a height between 8,000 and 12,000 feet. Planes with motors of 250 horse power (maximum) have ceilings at heights ranging from 12,000 to 15,000 feet. For airplanes with motors of more than 250 horse power, the ceiling is ordinarily higher than 15,000 feet, but not higher than 18,000 for most. A few airplanes, particularly military types, can attain 20,000 feet. Most planes which have a practical ceiling higher than 20,000 feet, are specially designed altitude ships, carrying superchargers for the motor or motors. Another feature which tends to limit practical airplane height is the effect of altitude on occupants. It has been found that above 15,000 feet the aviator's efficiency declines because of lack of oxygen, and above 18,000 feet it is necessary to employ an oxygen-breathing apparatus. The extreme cold and the rarefied atmosphere at greater height necessitate elaborate equipment for pilots and passengers. Equipment used by aviators making experimental flights to great altitudes is impracticable for commercial work.

Special film emulsion and color filters are used in nearly all mapping work. These were developed during the war, and their use with very little modification has been continued. A filter was originally used to

obtain sharp pictures under hazy atmospheric conditions. Experiments have shown that light of the longer wave lengths, that is, toward the red end of the spectrum, is less affected by haze than shorter wave-length light at the blue end of the spectrum. To photograph through haze it is therefore necessary to use a filter of a red or yellow color, which eliminates different amounts of the green, blue, and violet light. Because the emulsion on most commercial film is much more sensitive to blue light than to red, the use of a filter with such an emulsion would necessitate an exposure of prohibitive length. It is therefore necessary to use a special red-and yellow-sensitive film. Such film is known commercially as panchromatic; a film having extreme red sensitiveness is known as a red-sensitive film. Used with panchromatic film, filters have a tendency to increase the necessary exposure interval from two to several times that required without a filter, and the film must not only be red-sensitive, but must also be as rapid as possible.

The requirement of sharpness of definition adds importance to the film speed. As the writer has explained, it is convenient to use a lens of focal length as short as possible in order to observe the limits of scale requirement and practical airplane height. With decreased focal length, the size of the picture remaining constant, greater covering power is required. This, in turn, can only be achieved by decreasing the lens aperture, or, as it is commonly called, the lens speed. The speed of a lens, given numerically, is the ratio of the effective diameter of the opening through which the light passes, to the focal length. Inasmuch as the amount of light passing through an opening of specified diameter varies with the area, the speed of a lens at different apertures varies as the square of the aperture diameter, therefore, as the square of the speed-ratio figure. Lenses of 12-inch focal length give satisfactory covering at a speed of F. 4.5. A speed between F. 6.8 and F. 8.0 is required to obtain the same quality of definition with an 8-inch lens, depending on the characteristics of the lens. This necessitates two or three times the exposure time required for the larger aperture.

The most favorable condition regarding each of the factors mentioned is that which tends toward under-exposure of the negative. One must, therefore, make a compromise selection such that a certain minimum latent image is formed sufficient to develop into a printable picture within the maximum exposure period allowable. The possible exposure period is limited by the angular speed of airplane travel with reference to the ground. One seventy-fifth of a second is a maximum period for average conditions in mapping photography.

Another factor affecting the selection of film emulsion and filter is that of color differences important to be shown in the picture. This selection is determined by the purpose for which the picture is to be used. In artistic photography the purpose is to reproduce each color at its visual appearance of lightness or darkness. For example, it is incorrect to have a dark blue object appear in the picture as being lighter than a pale red object, although this is the result obtained by all amateurs using ordinary film without a filter. The use of filters in photography for detecting camouflage, during the war, is an example of what may be done in accentuating slight differences in colors of objects. It was found that green paint used for painting foliage camouflage reflects spectrum bands somewhat differently from green foliage itself. It was therefore possible to devise a filter which would transmit bands present in the foliage spectrum and be opaque to the paint spectrum. Thus the camouflage was rendered by a darker shade than that of foliage, and was more easily detected in photographs than by direct viewing with the naked eye. To accentuate differences between geological formation colors, it would be necessary to use a filter which would transmit the greater part of the light reflected from one formation and which would be opaque to that from another formation of only slightly different color. An investigation along such lines should be of considerable value, but, as far as the writer knows, little or nothing has been done.

For some purposes, particularly if the pictures are not to be viewed stereoscopically, it is desirable to have a shadow effect on the north side of the hills so that an appearance of relief can be seen in a single picture. This may be accomplished by taking the pictures shortly before or shortly after noon, but none of the shadows should be deep enough to obscure detail. In many pictures there is a shadow effect on the north slopes, caused not only by a difference in color of vegetation, but also by the decreased incident light intensity.

More or less difficulty is to be expected in flying an airplane over the desired course and in holding tilt down to a minimum. At the elevations commonly reached, wind velocities as high as 60 miles an hour are not exceptional, although there may be little or no wind on the ground surface. With wind of constant direction and velocity, the problem is comparatively simple, but more generally one has to contend with shifting winds. At an airplane speed of 90 miles an hour, considerable deviations from the required course may occur before the navigator is aware of them. Most navigators use a drift indicator of some type to show the actual direction of travel with reference to the ground. Some pilots are able

to take picture strips successfully while flying, using no equipment other than compass and altimeter. It is probable that the future will see more elaborate navigation equipment in common use, but at present there is considerable disagreement as to whether additional apparatus is necessary or desirable.

Some of the differences between airplane photographs and topographic maps, as a base for plotting field geology, may be mentioned. The great amount of detail shown on photographs enables one to pick out the particular feature in which he may be interested, and in this respect pictures have a greater variety of possible uses than topographic maps. The latter show only such features as were considered important by the topographer or by the organization for which the map was made.

The many small details of topography, vegetation, and culture make the determination of location comparatively easy. Nearly every location is near some recognizable feature of vegetation, rock outcrop, or road. An observer may meander above a small gulley and determine locations of geologic features as accurately as when traversing a ridge from which there is an extensive view. When using a topographic map, one generally finds it necessary to climb from a gulley to the adjacent ridge in order to determine a location accurately.

Geological lines are ordinarily traceable on pictures, by actual rock outcrops or by slight differences in soil coloration or vegetation color. Bands of slightly different soil color may be seen on pictures, though they are not apparent to a geologist when he is actually walking on the ground.

In this connection topographic detail is also an important aid in field mapping. This is best seen by examining two overlapping pictures under a stereoscope. For this reason, in most of the picture mapping done for geologists, it is specified that adjacent pictures in a strip shall overlap not less than 50 per cent. When the area common to two pictures is viewed under a stereoscope, the appearance is that of a small relief model of the territory, every detail of elevation being evident. When pictures are viewed stereoscopically, small ridges or breaks in slope, and trends in drainage alignment, may indicate structure, although these features are ordinarily too small to be seen on a well-made topographic map. In examining pictures of the Kern River district near Bakersfield, California, geologists have discovered topographic effects indicating faulting in territory which had been mapped previously in detail without the presence of such faults being suspected.

FIG. 1.—California coast west of Santa Barbara. Monocline of Tertiary beds dipping toward ocean at 45°. Cliffs along coast, dissected coastal plain bounded inland by resistant member. Alignment of seaweed in ocean due to structure. Scale: 1,500 feet per inch.

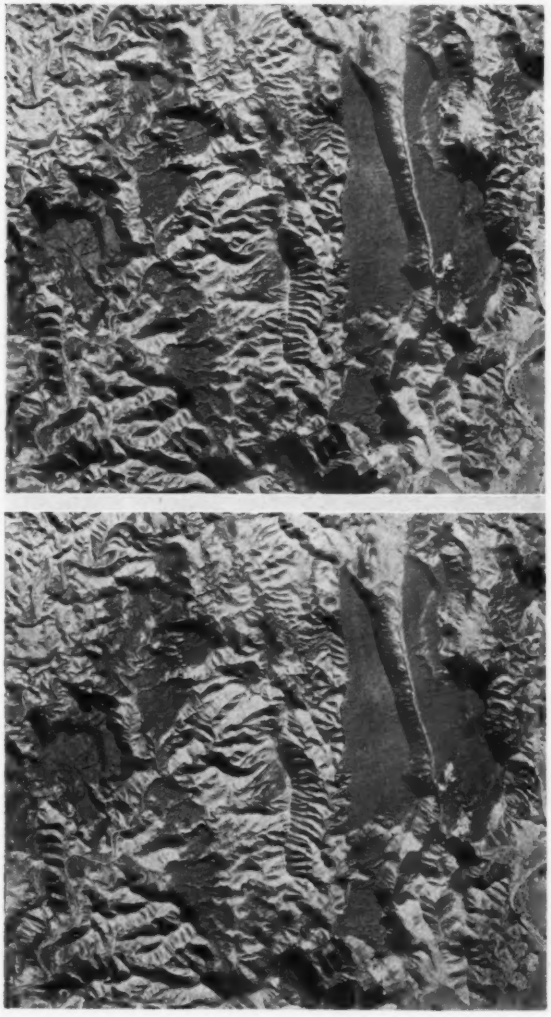

FIG. 2.—Soft Tertiary beds in Imperial County, California. Two prominent dip slopes of thin volcanic flows. To be viewed under stereoscope. Scale: 1,000 feet per inch.

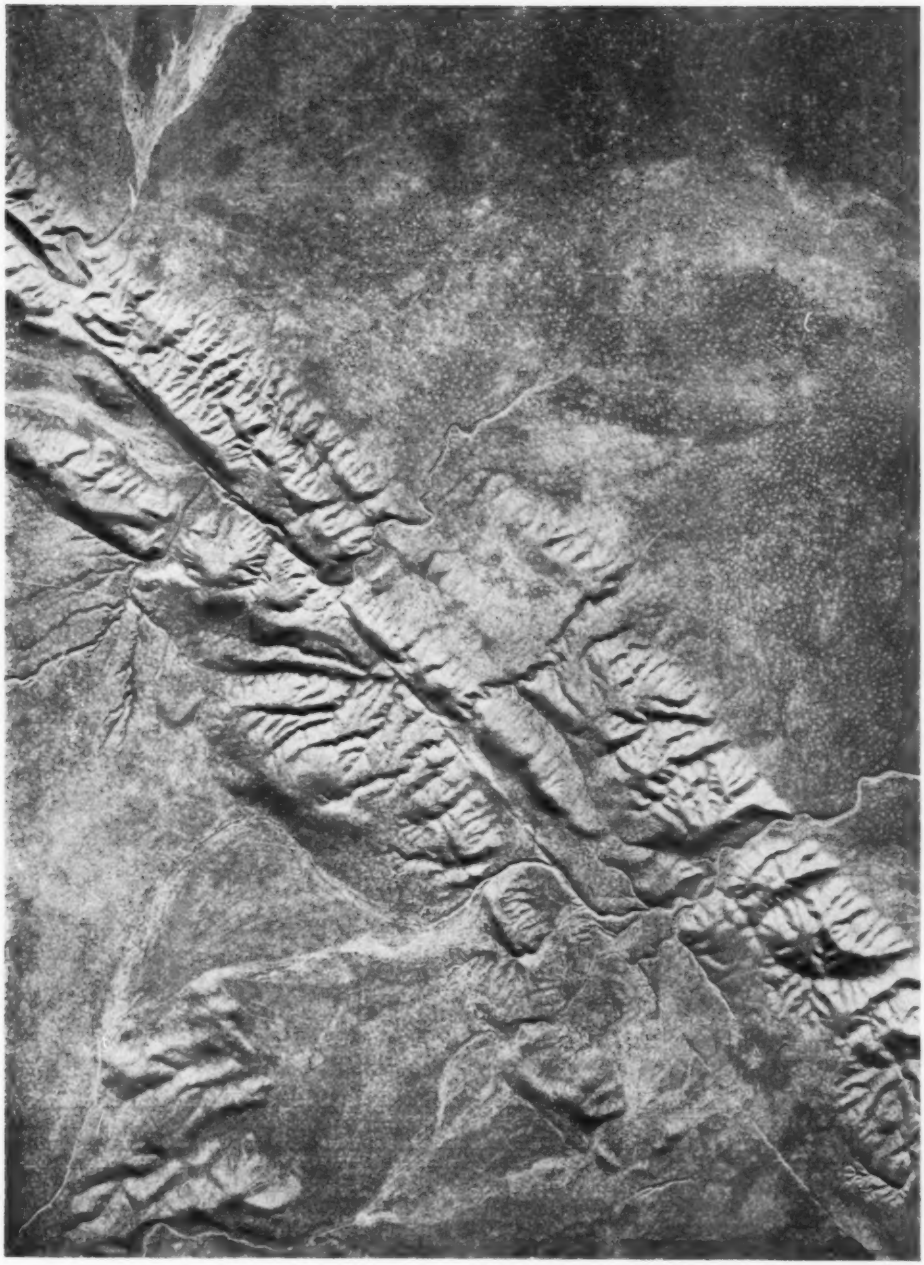

FIG. 3.—San Andreas fault in Carrizo plains, central California. Low hills of soft sediments with small-scale details of rift topography and offset drainage. Scale: 1,200 feet per inch.

An undesirable feature of airplane pictures, which is a necessary accompaniment to their stereoscopic value, is the so-called distortion because of the topography. A picture is a radial projection, instead of an isometric projection, such as an ordinary map. In a radial projection the distance of any point from the center of the picture is proportional to its elevation; thus, of two points of different elevations, the higher is shown relatively farther from the center than the lower point, and a line joining two such points is not in correct azimuth if the picture is placed so that radial lines from the center are all in correct azimuth. The amount of this topographic distortion depends on the ruggedness of the country and on the focal length of lens used in the camera. Shorter focal lengths cause a greater amount of distortion. Because of this distortion, one must rely on making locations for plotting data by recognizing features in the immediate vicinity, rather than by plotting intersections of compass sights to prominent points at a considerable distance, as is done when using ordinary maps.

Picture mosaics may be substituted for regional maps in the compilation of data from the individual pictures. All mosaics lack accuracy because of the topographic distortion in the individual prints from which they are made. Further distortion may be caused by the tilt of the camera at the time the picture was taken. If proper precautions in taking the picture are observed, the tilt ordinarily amounts to less than 3°. Except in very flat country, the topographic distortion is considerably greater than distortion due to tilt. The most commonly used type of mosaic is made by matching the various prints along lines of common points. Where there is much variation in elevation, such mosaics become less and less accurately matched, as the area included in a single sheet is increased. In order that the unavoidable errors of matching may be equally distributed, rather than allowed to accumulate from one print to the next, some form of map control is desirable. Inasmuch as radial lines from the center of a photograph to various points subtend true angles at the center point, the pictures may be used as a basis of a triangulation system by which the true position of control points is determined. This is commonly known as the radial-line method of control. The United States Geological Survey has used this method in compiling line maps of considerable accuracy, and has issued a booklet describing compilation of maps by this method. A map of this type may be used as a base on which a picture mosaic is laid. To make the individual pictures fit the control points on such a map, it is necessary to alter the size and shape of the prints used from the size and shape of the original neg-

atives. Such prints are known as rectified prints and are made in a projection printing machine, instead of on a contact printer. Some pictures may be rectified only by changing the scale of the print from that of the original negative. Such prints are "scale-corrected." In correcting others it may be necessary, however, to change the shape also, and for this purpose the negative and the paper carrier in the projection machine must each be tilted relative to the principal axis of the projection lens. Such prints are "tilt-corrected." If sufficient care is used in laying a controlled mosaic with scale- and tilt-corrected prints, the resulting accuracy is greatly increased as compared with that of an uncontrolled mosaic. This accuracy, however, is not comparable with that of points located by the use of transit and chain, as in ordinary ground surveys.

The data in a group of overlapping airplane pictures are sufficient for the construction of a topographic map of a very high degree of accuracy. Although methods of doing this, which require only accurate measurement of distances on the prints, have been devised, the amount of work necessary makes the cost prohibitive as compared with other methods of map-making. Recently, rather complicated machines have been devised for performing most of the necessary calculations, and maps of very much greater accuracy of detail, as compared with those made by ordinary field methods, should be available at moderate cost. At present there are two firms in the United States engaged in work of this type. The United States Geological Survey has recently bought a map-contouring machine of German origin, and is now experimenting to determine whether it will be practicable for the Survey to substitute topographic mapping from airplane pictures for previous field methods. The machine which the Survey is using provides for viewing a stereo pair of pictures in conjunction with a floating mark. By mechanical movements the mark is made to trace contours on the relief view seen by the observer, and at the same time a drawing mechanism traces out the contour to true scale and position on a map sheet. It is said that few contours made from pictures of a scale of 1,000 feet to the inch depart as much as 5 feet from their true elevation. In some large-scale maps actually made by this method, it is said that the contours are at no place in error more than 1 foot in elevation or more than 5 feet in plan.

EXAMPLE OF DEFLECTING DIAMOND-DRILL HOLES[1]

ROBERT DAVIS LONGYEAR[2]
Minneapolis, Minnesota

ABSTRACT

On a property on the Marquette Iron Range, Michigan, the iron formation overlying the ore was so much fractured that exploration had to be undertaken by means of angle holes from either side in more solid ground. All of the holes showed considerable curvature, one of them curving so much it was actually rising when completed. The curvature was initiated by increasing the pressure on the bit at the desired depth. Two of the holes were deflected at a considerable distance above the bottom, in order to explore new ground at depth without re-drilling the entire hole.

Because of the present interest of the oil industry in the subject of crooked holes, the following brief account of a diamond-drill exploration based on "crooked holes" may be timely.

The work was commenced in 1909 on a property on the Marquette Iron Range, Michigan. Here the Negaunee iron formation, 1,000 feet thick, dipping steeply toward the south, is much fractured beneath the glacial drift. The hypothesis was advanced that the fracturing was caused by slumping due to the concentration of the iron ore at depth.[3] But the extremely fractured condition made it difficult to drill vertical holes to test this hypothesis. It was therefore decided to drill angle holes from the Siamo slate on the north and the Goodrich quartzite on the south. Figures 1 and 2 show the geology and location of the drill holes, but the outlines of commercial iron ore within the iron formation have been omitted.

Hole 1 was commenced in the hanging-wall quartzite, pointing north at an angle of 60° from the horizontal. It was caused to flatten

[1]Read before the Association at the New Orleans meeting, March 21, 1930.

[2]President, E. J. Longyear Company.

[3]The generally accepted theory of the origin of most of the Lake Superior iron ores is that they have been formed by the action of meteoric water on the iron formations. The iron formations consist of different proportions of iron silicate, iron carbonate, chert, and hematite, locally called taconite, jasper, or ferruginous chert. Under the action of meteoric water, the iron is oxidized and the relatively more soluble silica removed by leaching, leaving behind a porous mass of hematite. John W. Gruner has recently advanced a slightly different theory, which will be discussed in a forthcoming paper in *Economic Geology* entitled "Hydrothermal Oxidation and Leaching Experiments and Their Bearing on the Origin of the Hematite-Limonite Ores of the Lake Superior Region."

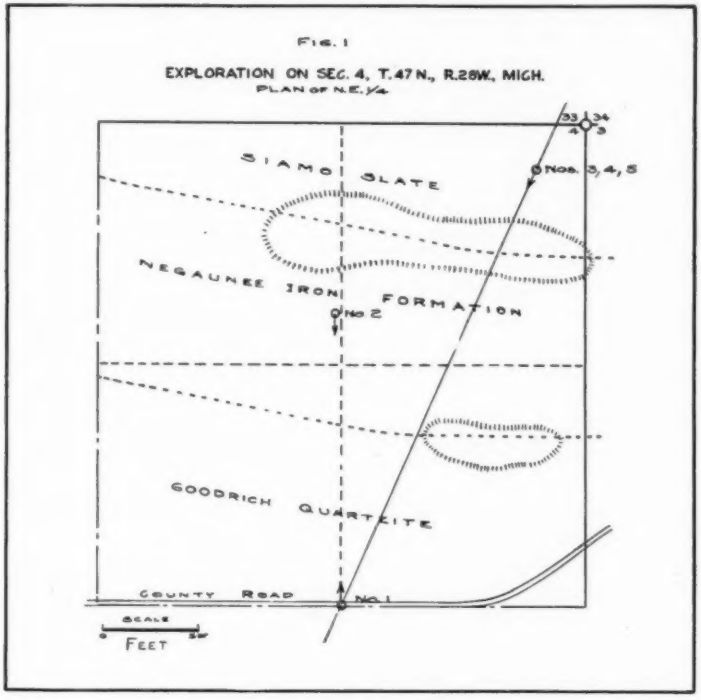

FIG. 1

at about 700 feet in depth, below which it continued in a gradual curve to the "bottom," at 2,091 feet, where it was pointing slightly above the horizontal. The results encouraged further exploration.

Hole 2 was drilled in an attempt to reach the ore through the overlying broken iron formation, but was stopped at 180 feet in favor of drilling cross-cutting holes from the north.

Hole 3 was commenced in the foot-wall slate at an angle of 60°, pointing S. 15° W. It was stopped at 782 feet in fractured jasper and ore. The hole flattened during drilling until at the bottom it was nearly horizontal.

Hole 4 was commenced at the same location at an angle of 85° from the horizontal and, on account of excess caving material, was stopped at 2,436 feet, still in foot-wall slate. The hole had been flattened until at

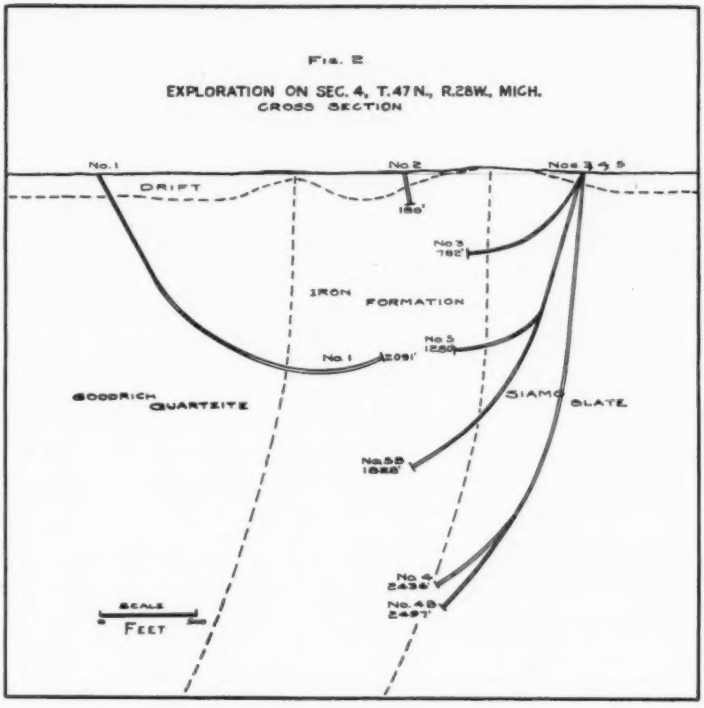

FIG. 2

the bottom it lay at an angle of 36° from the horizontal. In order not to re-drill the entire hole, a deflecting wedge was placed at 1,879 feet to steepen the angle, and hole 4-B was drilled from this point to 2,497 feet, but was stopped in the same fractured horizon as hole 4. The angle at the bottom of hole 4-B was 49° from the horizontal.

Hole 5 was drilled at an angle of 70° from the horizontal to explore territory between hole 3 and hole 4. At about 750 feet it was caused to flatten, and at the bottom, 1,280 feet, it lay at an angle of 7° from the horizontal. To make use of the depth already gained in hole 5, hole 5-B was drilled by deflecting hole 5 at 770 feet. This hole was steeper and was completed in lean ore at a depth of 1,828 feet, the angle being 31°.

Angle tests were made by means of a hydrofluoric-acid tube. On account of the magnetic character of the rock, compass readings of the

course of the hole could not be taken. The section as drawn in Figure 2 is based on the assumption that holes 3, 4, 4-B, 5, and 5-B were in the same vertical plane, an assumption which is believed to be substantially correct.

Table I is a record of the angles, corrected for error due to capillary attraction.

TABLE I

Depth (Feet)	*Angle from Horizontal (Degrees)*	*Depth (Feet)*	*Angle from Horizontal (Degrees)*	*Depth (Feet)*	*Angle from Horizontal (Degrees)*
HOLE 1		HOLE 4 (*Continued*)		HOLE 5 (*Continued*)	
0	61	1,550	69	500	74
710	44	1,600	68	550	74
1,000	32	1,650	67	600	75
1,130	26	1,700	65	650	75
1,340	16	1,750	62	700	77
1,550	6	1,800	62	750	71
1,640	1	1,850	58	770	69
1,692	0	1,950	52	800	64
1,860	−12	2,000	48	890	45
HOLE 3		2,050	45	1,000	27
		2,100	45	1,100	13
0	60	2,150	43	1,200	11
320	53	2,250	41	1,280	7
410	43	2,350	36		
500	32	HOLE 4-B		HOLE 5-B	
590	17				
680	13	1,850	58	770	69
HOLE 4		1,880	59	800	69
		1,900	58	850	69
0	85	1,950	56	900	69
100	85	2,000	55	960	69
900	85	2,050	55	1,085	62
1,000	84	2,150	54	1,135	61
1,050	84	2,250	52	1,200	57
1,100	83	2,350	50	1,261	55
1,150	82	2,450	49	1,335	51
1,200	81	HOLE 5		1,393	47
1,250	78			1,450	46
1,300	77	0	70	1,505	43
1,350	75	118	71	1,560	40
1,400	74	250	70	1,602	39
1,450	73	350	72	1,670	36
1,500	71	450	74	1,760	31

The most interesting feature of this work was the controlled deflection of the holes both with and without the use of wedges.

The natural tendency of diamond-drill holes cutting the strata at a fairly large angle is to turn in a direction normal to the plane of strat-

ification. In this work, this tendency was purposely accentuated by increasing the pressure at the depths where it was desired to start the flattening of the holes, the object being to cross-cut the formation more rapidly.

In the wedge method, a steel wedge was lowered into the hole with the drill rods and cemented in place. The wedge was approximately oriented by marking the rods as they were lowered into the hole. The entire exploration presented considerable difficulty, on account of the extremely brecciated nature of the ground in this locality, necessitating much reaming, casing, and cementing.

The process of deflection of diamond-drill holes by wedges has been very much improved since this work was done.[1] Wedges can now be purchased which can be readily oriented without using the doubtful process of "lining the rods." This orienting is accomplished by (1) placing a "drive wedge" in the hole at the desired point, (2) surveying with a special clinometer the position of the upper beveled surface of the drive wedge, (3) adjusting the relative position of the pilot wedge with respect to the deflecting wedge so as to correspond with the observed position of the drive wedge, and (4) placing the deflecting wedge in the hole so that the bevel on the pilot wedge is properly located on the bevel on the drive wedge. Vertical diamond-drill holes, more than 3,000 feet in depth, have been drilled with excellent directional control by the skilful use of these wedges to correct tendencies to divergence from the vertical.

[1] O. Hall and V. P. Row, "Wedging Diamond Drill Holes," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 63 (1920), pp. 413-18.

GEOLOGICAL NOTES

USE OF THIN BENTONITE BEDS IN MAPPING STRUCTURE, ROSENCRANZ AREA, KANSAS AND COLORADO[1]

Mapping the structure lying in Cheyenne County, Kansas, and Yuma County, Colorado, now being tested by the Phillips Petroleum Company, required the development and use of methods which are of special interest at this time, as they will probably be used to map other structures in the same region presenting similar problems.

The surface formations in the Rosencranz area include sandstones, sandy limestones, and clays of Tertiary age and the Pierre shale of the Upper Cretaceous system. The Tertiary formations have not been proved to be reliable indicators of the subsurface structure in this region; consequently, it was necessary to map the structure from data obtained from the shales.

The shale exposures being much weathered, it was not considered sufficient to map the structure on dip-and-strike observations alone. In general the dips were low, and later work showed a great many local variations in dip which would have been misleading. The problem, therefore, was to find beds or horizon markers in the shale section exposed which could be used as a datum in the determination of the structural conditions.

Others who have had experience with the problem have been almost unanimous in declaring it impossible to find such beds. The writer quotes Kirtley Mather, James Gilluly, and Ralph G. Lusk.[2]

> The absence of persistent "key beds" in the Pierre shale makes it impossible to determine from isolated outcrops the exact stratigraphic position of observed strata within this thick mass of sediments. The rapid and great variation in individual zones, as observed along the strike parallel to the mountain front, presumably is equaled by changes in the same beds eastward from their outcrops. In general, however, the lower fourth of this formation seems to be largely dark carbonaceous fissile shale with only a few sandy beds, but with many thin seams of bentonite.

[1]Read before the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, October 4, 1929. Manuscript received by the editor, May 10, 1930.

[2]"Geology and Oil and Gas Prospects of Northeastern Colorado," *U. S. Geol. Survey Bull. 796-B* (1928), p. 87.

The shale section exposed west of the Rosencranz area in the vicinity of Beecher Island, Colorado, contains several bentonite beds whose average thickness is approximately 2 inches. Previous work done in this area by the writer and by D. A. Knight had shown that it was possible to correlate isolated exposures by observing the intervals between these beds. This section was present in some parts of the Rosencranz area, but seemed to have been eroded to such an extent that it was not possible to make use of it. Reconnaissance in the Rosencranz area soon made it evident that bentonite beds of any appreciable thickness were of extremely rare occurrence; however, the reconnaissance did reveal three bentonite beds, or streaks, exposed rather generally, one having an average thickness of approximately 1 inch, and the other two less than ¼ inch. The interval between the two thin beds was 5½ feet and between the lower of these and the thicker bed about 28 feet. The lower bed was used for datum.

To attempt to map structure on key beds of such seemingly hopeless insignificance seemed at first outside the limits of reasonable reliability and accuracy. They were, however, the only features in the exposed section which could be followed across the area and recognized in isolated exposures of the shale. Use of these beds demonstrated several facts which had not been generally recognized. The first fact was that the structure of the area could be accurately determined through their use, and the second was that such beds, if used with due precaution, were in many respects more reliable and effective horizon markers than thick ledges of outcropping limestones or sandstones in other areas.

Because the writer has been asked several times to relate how the Rosencranz structure was mapped without depending entirely upon dip-and-strike observations, he feels that a description of the method followed would be of interest.

As the first step in the reconnaissance of the area, a detailed section was measured at a place where the greatest thickness of shale was exposed. This section was measured with the greatest accuracy and the most careful attention to seemingly insignificant details (Fig. 1).

Before the section was measured, the shales were exposed by digging trenches deep enough to penetrate the unweathered material. The depth required for this ranged from 1 foot to 3 feet where there were not surface deposits of recent materials, and deeper where such deposits covered the shales.

Laborers obtained locally were used for this work and the geologist remained with them while they were so engaged to observe and note

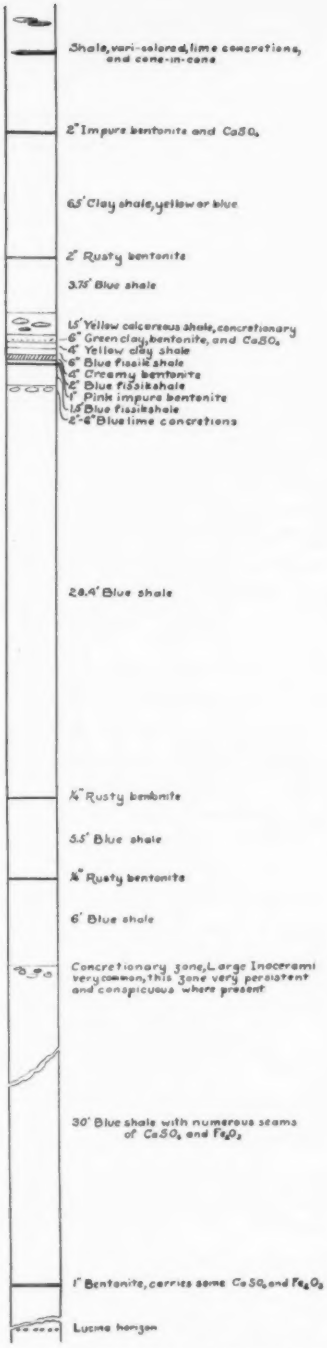
Shale, vari-colored, lime concretions, and cone-in-cone
2" Impure bentonite and $CaSO_4$
65' Clay shale, yellow or blue
2" Rusty bentonite
3.75' Blue shale
15' Yellow calcareous shale, concretionary
6" Green clay, bentonite, and $CaSO_4$
4" Yellow clay shale
6" Blue fissile shale
4" Creamy bentonite
2" Blue fissile shale
1" Pink impure bentonite
1.5 Blue fissile shale
2'-6" Blue lime concretions
28.4' Blue shale
4" Rusty bentonite
5.5' Blue shale
4" Rusty bentonite
6' Blue shale
Concretionary zone, Large Inocerami very common, this zone very persistent and conspicuous where present
30' Blue shale with numerous seams of $CaSO_4$ and Fe_2O_3
1" Bentonite, carries some $CaSO_4$ and Fe_2O_3
Lucina horizon

FIG. 1.—Detailed section of Pierre shale beds exposed in Rosencranz area. Thickness shown in feet and inches.

each occurrence of any break or change in the character of the shale while the surfaces were fresh. When the section had been completely uncovered and such correlations had been made in the field as were necessary to obtain the greatest possible section, a transit was set up and the section measured with that instrument.

After this section had been measured it was noticed that the three bentonite beds already mentioned were the only features which showed any promise of being present throughout the area.

Similar sections were then measured at three other strategically located points. The sections so obtained were plotted in the office on a scale of ½ inch = 1 foot and a comparison of the four sections was made. Figure 2 shows the correlation of the four measured sections and illustrates the regularity of the intervals between the three thin beds. Other features, notably the concretionary layers, were observed, but none of these was in evidence in all the four sections. From this study it became evident that the only way in which the area could be mapped was by the use of these very thin beds, supplemented, where possible, with three-point dip-and-strike observations.

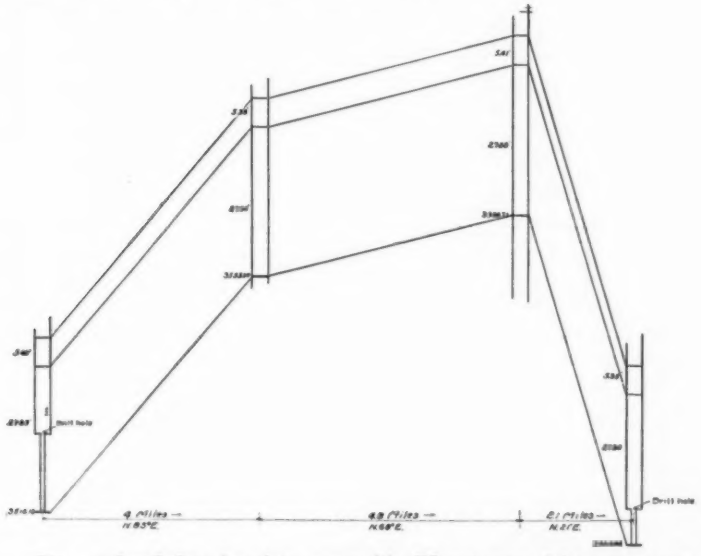

FIG. 2.—Correlation of sections measured in different parts of Rosencranz area. Correlations are based on regular intervals between key beds. Figure at base of each section shows feet above sea-level. Thickness of intervals shown in feet.

In some parts of the area deep arroyos cut by the present erosion afforded good exposures, but in other places the topography was of the typical rolling type of low relief ordinarily found in shale areas. This made it necessary to develop some means whereby the sections exposed could be extended to include two, or if possible, three key beds. For this purpose an earth auger was used. By extending its length, by the use of short lengths of pipe, holes were bored to a maximum depth of 25 feet. The results of these borings were very satisfactory and it was possible thus to obtain accurate sections of useful length. The elevation of each of these drill holes was determined by tying it to a stadia traverse and the depth to the datum or key bed encountered in drilling was obtained by measuring the length of the auger used to obtain cuttings from the bed. As it was necessary to pull the bit from the hole after boring 5 or 6 inches, the cuttings were available continuously for inspection through the entire operation. As the operators became experienced in drilling they were able to notice at once any change in the shale and could easily determine when a bentonite bed was penetrated by reason of the great difference in the drilling. Removal of the bit when such a change was noticed invariably brought up cuttings of bentonite. Most of the holes were drilled as near as possible to outcrops of the beds thought to be the upper two, and if the interval to the bed encountered in drilling approximated 28 feet, as anticipated, the elevation of the datum bed at that point was accepted. This procedure was followed until sections had been obtained wherever it was possible and necessary. The measurements so obtained were plotted and checked against the key sections.

Where it was possible, the actual outcrops of the three beds were followed and their elevations were determined at close intervals. In addition, more than a hundred holes were drilled to supply datum elevations where key beds were covered and to aid in the identification of isolated exposures. Some of the drill holes were only a few feet deep; most of them ranged from 9 to 15 feet. A pit was dug and the bed thus opened for more careful inspection. One of the most striking features was the uniformity in color, thickness, and general appearance of the datum bed in these unweathered exposures.

As a matter of fact, had this larger bed been the only bed it would have been possible to determine the structure from observations on it alone. However, in view of the fact that the work would probably be checked and be given the most careful scrutiny, it was deemed advisable to substantiate it wherever possible. For this reason, extra time and effort were spent to measure the interval to the upper beds and between

them, thus checking the identity of the datum bed. The two upper beds were so very thin and hard to recognize that it might have been possible to make a mistake in identifying them alone. The regularity of the two intervals, the 5½-foot interval between the upper beds and the 28-foot interval to the datum bed, practically eliminated any chance for error in the identification of the beds.

Summary.—The method consisted simply of identifying the thin beds of bentonite by measuring the shale intervals between them. The regularity of the intervals made it possible to identify the beds. The uniformity of bentonite beds through long distances is due, of course, to the nature of the material and its deposition.[1]

The uniformity of these thin beds through long distances tempted the writer to investigate their persistence further and as the result of the investigation he is convinced that a bentonite bed exposed in the vicinity of Beecher Island, Colorado, having very pronounced characteristics, can be identified at a point 70 miles distant, near Sharon Springs, Kansas. Figure 1 shows a detailed description of the bed.

This statement is, of course, open to argument, but it is made only after the most careful consideration. The outcrops of the beds were carefully studied and measured at both places and photographs of each were taken. The photographs of the two exposures, taken under similar light conditions and with the camera set at equal distances from the subjects, are so nearly alike that they seem to be pictures of the same bed.

These correlations are substantiated by paleontological evidence, though the writer believes it would be safer to substantiate the paleontology by the use of lithology.

CHARLES H. RANKIN, JR.[2]

CONTINENTAL OIL COMPANY
DENVER, COLORADO
October, 1929

STRATIGRAPHIC NAMES[3]

INTRODUCTION

Although he may see the necessity for uniformity in the use of stratigraphic names and other technical geologic terms, the average

[1]W. H. Twenhofel, *Treatise on Sedimentation* (Williams and Wilkins, Baltimore, 1926), pp. 205-09.

[2]Introduced by Charles S. Lavington.

[3]Published by permission of the director, U. S. Geological Survey.

geologist, like the average citizen in other walks of life, is much more willing to agree to rules for the government of other people than he is to accept any restriction of his own actions. This very human characteristic is partly responsible for the duplication and multiplication of names, the varying definitions, the discordant classifications, and other confusing features with which stratigraphic literature is afflicted. It is recognized, however, that stratigraphic nomenclature is necessarily somewhat temporary and unstable because exploratory and descriptive geology with the presentation of preliminary economic results is ordinarily far in advance of accurate correlation; consequently, either old names are misapplied or new names that are given are later found unnecessary.

COMMITTEE ON STRATIGRAPHIC NOMENCLATURE

At a meeting of the Association of State Geologists held in Washington, February, 1930, a Committee on Stratigraphic Nomenclature was appointed, consisting of Geo. H. Ashley, C. N. Gould, and R. C. Moore. On request from the state geologists, coöperating committees were later designated by the United States Geological Survey, The American Association of Petroleum Geologists, and the Geological Society of America, as follows: H. D. Miser, T. W. Stanton, and G. W. Stose, for the Geological Survey; M. G. Cheney, C. J. Hares, and A. I. Levorsen, for the petroleum geologists; and J. J. Galloway, B. F. Howell, and W. H. Twenhofel, for the Geological Society of America. A joint meeting of these committees, with C. N. Gould as chairman, held in the office of the Illinois Geological Survey at Urbana, Illinois, on April 30, 1930, was attended by the geologists here mentioned except Levorsen and Stose, who were unable to be present, and the representatives of the Geological Society of America, who had not yet been appointed. After general discussion of the problem of stratigraphic nomenclature several subcommittees were appointed to continue the study of various phases of the subject, and it was voted to request T. W. Stanton to write a paper on stratigraphic names calling attention to the data on this topic available to geologists generally in the records of the United States Geological Survey. It was also suggested that the paper should be offered to this *Bulletin* for publication. It is accordingly now published.

DEVELOPMENT OF NOMENCLATURE AND CLASSIFICATION

Perhaps it will be helpful to give a brief review of the experience of the United States Geological Survey in its attempt to secure uniformity of stratigraphic nomenclature and classification in its own publications.

Early in its history the Geological Survey assumed as one of its principal duties the preparation of a geologic atlas of the United States, and field work for separate sheets of this project was promptly begun in many widely separated parts of the country. Before any of the sheets was published[1] many differences of opinion developed concerning the form of publication, the classification and nomenclature of the rocks, the coloring and notation of the maps, and many other details. Such differences of opinion were inevitable when the work was done simultaneously by many geologists of different temperaments and with widely different training in such diverse areas as the Appalachian region from Maryland to Alabama, the Rocky Mountains in Colorado and Montana, and the Sierra Nevada, but as it was planned that the results of their work were to be incorporated in a single great atlas of the United States, it was necessary that there should be at least a semblance of uniformity in the methods of presentation. It was for the Geologic Atlas that the rules of nomenclature and classification of geologic formations were devised by the Geological Survey, though they have since been applied to all of its publications.

Previously a general scheme of classification and a color scheme for geologic cartography had been promulgated by Director Powell[2] at the beginning of his administration. This statement by Powell and the records of two Geological Survey conferences subsequently called by him[3] and Director Walcott[4] throw interesting light on the history of geologic nomenclature in the United States. At the first of these conferences the record states

there were present, besides the Director, the following geologists and lithologists: C. Whitman Cross, J. S. Diller, C. E. Dutton, George H. Eldridge, B. K. Emerson, S. F. Emmons, G. K. Gilbert, Arnold Hague, W. H. Holmes, Joseph P. Iddings, W. J. McGee, A. C. Peale, Raphael Pumpelly, C. R. Van Hise, Walter H. Weed, George H. Williams, and Bailey Willis. In addition was Mr. C. D. Walcott, a member of the paleontologic branch whose recent work has been stratigraphic.

[1]The first group of folios of the Geologic Atlas was issued in 1894.

[2]*U. S. Geol. Survey 2nd Ann. Rept.* (1882), pp. XL-LIII.

[3]*U. S. Geol. Survey 10th Ann. Rept.* (1890), pp. 63-79.

[4]*U. S. Geol. Survey 24th Ann. Rept.* (1903), pp. 21-27.

This last sentence may be taken as a faint recognition of the fact that even then some paleontologists were beginning to become geologists.

Fourteen years later, when C. D. Walcott had become director of the Geological Survey, all members of the Survey's scientific staff were invited to submit suggestions for amending the rules of nomenclature, and the task of digesting these suggestions and of making a complete revision of the rules was delegated to a special committee consisting of

G. K. Gilbert (chairman), W. B. Clark, Whitman Cross, C. W. Hayes, T. W. Stanton, H. S. Williams, and Bailey Willis, and near the close of its work C. R. Van Hise was added. Mr. F. B. Weeks attended to the preliminary correspondence and subsequently acted as secretary to the committee.

After a series of meetings held in 1902, the committee prepared a preliminary report, including a tentative draft of proposed rules, which was circulated among the other geologists and paleontologists of the Survey for criticism.

With the criticisms and suggestions thus obtained the committee resumed its work in February, 1903, holding a series of meetings, reconsidering all parts of the code of rules, and preparing a final draft. That draft, after revision by the director, was promulgated in March, as a code of regulations for the making of the Geologic Atlas of the United States.

With slight modifications it is currently applied to all Geological Survey publications.

It may be of interest to notice the changes in major elements of classification between 1890 and 1903 as shown in the Tenth and Twenty-fourth Annual Reports.

The Tenth Report recognizes for cartographic purposes

four great classes of rocks, viz.: (a) fossiliferous clastic rocks, (b) superficial deposits, (c) ancient crystalline rocks, and (d) volcanic rocks.

The classification of the Twenty-fourth Report recognizes only

three great classes of rocks, viz.: (a) *sedimentary*, including all rocks formed by aqueous, organic, glacial, and eolian agencies; (b) *igneous*, including all rocks that have been solidified from a molten condition, both volcanic and plutonic; (c) *metamorphic*, including altered rocks of either sedimentary or igneous origin in which the acquired are more prominent than the original characteristics, together with ancient schists and gneisses of uncertain origin. There may also be recognized in the legends of the maps unclassified deposits, such as talus, landslides, veins, etc., which may not fall within the above-enumerated genetic classes.

There were also several changes in the list of systems or periods adopted which may be shown in tabular form.

Tenth Annual Report	*Twenty-fourth Annual Report*	
Pleistocene	Quaternary	Recent
		Pleistocene
Neocene	Tertiary	Pliocene
		Miocene
Eocene		Oligocene
		Eocene
Cretaceous	Cretaceous	
Jura-Trias	Jurassic	
	Triassic	
Carboniferous	Carboniferous	Permian
		Pennsylvanian
		Mississippian
Devonian	Devonian	
Silurian	Silurian	
	Ordovician	
Cambrian	Cambrian	Saratogan[1]
		Acadian
		Georgian[2]
Algonkian	Algonkian	
Archean	Archean	

[1]Now replaced by St. Croixan.
[2]Now replaced by Waucoban.

NEW PERIODS PROPOSED

About 25 years ago Chamberlin and Salisbury's *Geology* was published, and in that work Comanchean, Permian, Pennsylvanian, and Mississippian were raised to the rank of system or period terms. Permian, of course, had long been so used in Europe. The fashion of proposing new period names then inaugurated was especially prevalent for

the next 6 or 8 years and resulted in the proposal of Tennesseean, Waverlyan, Cincinnatian, Canadian, Ozarkian, Waucoban, Acadian, St. Croixan, and perhaps others as coördinates of Cambrian, Devonian, Jurassic, et cetera. There have also been several varying proposals for the subdivision of the Tertiary into two, three, or four periods. These new proposals had become so numerous and the discussion of them so general that it was thought desirable to try to learn the consensus of opinion concerning them. In 1915, therefore, the Committee on Geologic Names, with the permission of the chief geologist, sent out a questionnaire to 258 geologists, of whom 96 were members of the Geological Survey, 42 were state officials, and 120 were teachers and other professional geologists. A total of 113 replies was received covering the desirability of new newly proposed periods, with opinions on the general principles of classification and nomenclature, the definitions of certain of the periods, whether all period names should end in *ic*, et cetera. The vote was about four to one against the last proposal, which was then filling geologic literature with such uncouth words as Cretacic, Ordovicic, Permic, et cetera. Naturally geologists expressed opinions only on topics in which they were especially interested. The highest vote recorded on a single topic was about 75. On others it was less than 40.

The results of that straw vote were never published, partly because the World War, which was then on and soon involved the United States, turned the attention of all geologists to matters which were directly connected with economic and political problems. It was also evident from the opinions received that at that time there was no general urgent demand for a radical revision of the classification used by the Geological Survey. It is true that 33 were in favor of dividing Carboniferous, and approximately the same number would recognize Permian, Pennsylvanian, and Mississippian as periods, but 26 would retain Carboniferous as a period name, and 2 were in doubt. On Comanchean as a period there were 21 for and 29 against. These four terms had gained considerable currency on account of their use in Chamberlin and Salisbury's manual. On the other proposed period names the vote was as follows.

	For	*Against*	*Doubtful*
Ozarkian	6	39	6
Canadian	10	31	2
Waverlyan	4	33	—
Tennesseean	4	33	—
Cincinnatian	3	49	—
St. Croixan	3	42	3
Acadian	3	42	3
Waucoban	3	42	3

On some of these questions views have doubtless changed in the last 15 years, and the time may now be ripe for accepting some of the newer proposals, but names of periods of geologic time and of systems of rocks should be of world-wide application, and for that reason I think that an attempt should be made to reach an international agreement on them, preferably through the Geological Congress. Of course it is necessary to make some approach to an agreement among ourselves before appealing to geologists of other countries. This is also true of the larger era terms. The Geological Survey uses Cenozoic, Mesozoic, Paleozoic, and Proterozoic, but several other era terms are elsewhere in current use, and some of these involve different definitions of some of the terms that are in most general use.

TIME AND ROCK TERMS

The following general statements about time terms and rock terms are quoted from Miss Wilmarth's "Geologic Time Classification of the United States Geological Survey."[1]

> The geological *eras* of the earth's history are divided into smaller time units, generally called *periods*, and the periods are divided into still smaller time units called *epochs*. In the nomenclature adopted by the Geological Survey the rocks formed during a geologic period constitute a geologic *system*, and the rocks formed during a geologic epoch constitute a *series*. Or the explanation may be reversed, and we may say that the time covered by a geologic system constitutes a geologic period, and the time covered by a geologic series constitutes a geologic epoch. * * * *
>
> For purposes of mapping and stratigraphy the series are divided into smaller units called *formations*, and many formations are divided into *members* and *lentils*. Several formations may also be assembled into a *group*. It might be useful to have a separate term corresponding to each of these rock units, but no such terms have yet been adopted, and in Geological Survey publications the single term *epoch* is used for all subdivisions of periods, whether they correspond to series, groups, formations, or members.

DISCRIMINATION AND NAMING OF FORMATIONS

In all classes of rocks the unit of mapping is the formation, which is therefore primarily a lithologic unit, but experience has shown that gross lithologic characters are not always a safe guide in delimiting formations. For that reason the geologist is instructed to draw the lines of separation of sedimentary formations where lithologic characters change or where there are breaks in the continuity of sedimentation or other evidences of important geologic events so as to give the formations

[1] *U. S. Geol. Survey Bull. 769* (1925), pp. 3, 4.

the greatest practicable unity of constitution, and in determining this unity of constitution he is advised to consider all available lines of evidence, including paleontology.

The fact that formations are all called units does not imply that they are comparable in thickness or in the length of time or importance of events recorded. One formation may be a mile thick and another even in the same general section only a foot thick; nevertheless, each may be mapped separately and appropriately called a formation. It is true that members and lentils are also mapped, but they receive a different designation simply because they are subordinate to a formation. It is a matter of relative rank. The graduated sequence of terms is system, series, group, formation, member. It is not permissible to have a series within a series, a group subordinate to a group, a formation containing other formations, or a member of a member. It is permissible to name the separate beds or strata or layers of a member, but when very detailed stratigraphic work is done it may happen that the list of terms is not long enough to cover all the categories recognized.

After being defined and named,

the formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic character, its stratigraphic association, and its contained fossils.

In naming sedimentary formations, the most desirable form of name consists of two parts, one of which is geographic and the other lithologic, such as Dakota sandstone. If the formation is not wholly or predominantly of one kind of rock, so that no single lithologic designation is appropriate, the word formation should take the place of the lithologic part of the name, as Mesaverde formation. Names taken from natural features are preferable, and brief names (of only one word) are desirable, but experience has shown that there may be a dearth of available names of places on or very near a point where the formation is typically developed and that it is thus necessary to accept names that are not the most desirable in form or euphony or those that are not based on the most complete and typical development of the formation. Members and other subdivisions are named in the same manner as formations, but in the legend of a map, in headings, columnar sections, and other such conspicuous places, the term "member," et cetera, should be added to the geographic and lithologic designation.

In the application of names to members, formations, and larger aggregates of strata, the law of priority shall generally be observed, but a name that has become well established in use shall not be displaced by a term not well

known merely on account of priority. In general, a newly defined formation shall not receive a name that has been previously used in a different sense.

In the naming of a newly constituted aggregate a geographic term should be chosen which has not previously been applied to a formation or aggregate; except (1) that the rank of a name may be changed without changing its stratigraphic inclusion, and (2) that the redefinition of an aggregate does not necessarily render renaming advisable.

The ideal condition sought by the two rules here quoted is that each name used shall be applied to only one unit or aggregate and that each aggregate or unit shall have only one name. The exceptions recognize the facts: (1) that rocks which at one time and in one area are treated as a formation may at another time or in another area be treated as a member or a group without changing the geographic part of the name; and (2) that minor modifications of the boundaries of a unit of any rank may be made without necessarily changing the name of the unit. It has sometimes been found expedient to permit the duplicate use of the same name for two different units if they are widely separated geographically or stratigraphically and if it is believed that they are strictly local in distribution. The elimination of many known synonyms is prevented or long delayed by local or political or personal considerations.

The method of naming igneous and metamorphic rocks is similar to that of naming sediments except that the petrographic terms are much more important and it is ordinarily not necessary to use geographic names unless there is more than one unit of the same kind of rock in the area described.

One more paragraph of the Geological Survey's "rules" is perhaps worthy of quotation, though its subject-matter is partly included in preceding statements. It is as follows.

Within the systems smaller aggregates of formations may be recognized, which shall be called *series*, and these may be divided into subordinate *groups* of formations. Groups may also be constituted without the recognition of series. These minor aggregates should be formed so as to express the natural relations of the formations of the particular province rather than to conform with divisions recognized elsewhere, though they may often prove to have a wider distribution.

The paraphrases and quotations here assembled exemplify the principles and practice of geologic nomenclature and classification adopted by the United States Geological Survey. Their application to papers submitted for publication is administered by the Committee on Geologic Names, which was organized in 1903. The work of the committee is, of course, subject to approval by the chief geologist.

INFORMATION ON NAMES AVAILABLE TO GEOLOGISTS

M. Grace Wilmarth, who has been the efficient secretary of the committee since 1906, has built up a system of files which embody, not only an index to the work of the committee throughout its history but also a complex index to the stratigraphic literature of the United States so far as names and classification are concerned. The Geological Survey is therefore prepared to give geologists prompt answers to many of their nomenclatural and stratigraphic questions, such as whether a particular geographic name has had previous use as a stratigraphic name; what are the original and current definitions of a particular formation or aggregate, especially if it has been described in Survey publications; the currently accepted age or classification of any particular unit; references to descriptions of stratigraphic sections of a restricted region; and other similar general or specific matters that are included in the committee's records.

The committee, of course, is not authorized or qualified to approve or recommend any new names or classifications submitted by correspondents of the Survey. Ordinarily the data offered are too meager to form the basis even of an opinion concerning the validity of the proposal. If a geologist wishes to make public acknowledgment of information furnished in reply to his queries, he should be careful to indicate the nature of the help received. For example, in proposing a new name an appropriate footnote would be "Name available (or free or not preoccupied) according to records of the Committee on Geologic Names, U. S. Geological Survey." If an author's conscience prompts him to mention other material received from the committee a simple statement of its nature is sufficient.

T. W. STANTON[1]

WASHINGTON D. C.
June 30, 1930

SULPHUR DOME, CALCASIEU PARISH, LOUISIANA[2]

INTRODUCTION

For many years the Sulphur salt dome was the greatest sulphur producer in the world. Now it is one of the largest oil-producing fields

[1]Chairman, Committee on Geologic Names, U. S. Geological Survey. Introduced by Charles N. Gould.

[2]Published by permission of W. R. Keever, vice-president, The Union Sulphur Company, Sulphur, Louisiana.

of the Louisiana Gulf Coast, and has still brighter prospects for the future.

LOCATION

Sulphur salt dome is located in the northeastern part of Calcasieu Parish, Louisiana, in the north half of Sec. 29, T. 9 S., R. 10 W. It is 15 miles west of Lake Charles and 2½ miles from the town of Sulphur.

HISTORY

The presence of sulphur in this dome was known for many years prior to the time that commercial production began in 1903. Millions of tons of sulphur were removed, and in 1924 the deposit became exhausted. Oil was then discovered on the flanks of the dome, and the drilling for oil began in the summer of 1925. Up to the present fifty wells have been drilled on the south and west sides of the dome. The north and east sides have not been tested.

PREVIOUS REPORT

Some of the geological features of this field were described by P. K. Kelley[1] shortly before the beginning of the commercial production of oil.

PHYSIOGRAPHY

The topographic features of this area have been changed somewhat by the mining operations of the Union Sulphur Company. Originally, the area was covered by a marsh, later known as Sulphur Mine marsh. On the north side a low ridge projected into the marsh. The elevation at the highest point on the ridge was a little more than 20 feet above sea-level. After mining operations began, this marsh, which covered an area of approximately 8,000 acres, was drained and tilled.

Such enormous quantities of sulphur were removed that the top of the dome caved. The crater was filled with earth, and at present there is a mound approximately 15 feet high over the center of the dome. The mound is known locally as "the hill."

GEOLOGY

Surface.—The surface beds of this general region are clays and sands which belong to the Beaumont member of the Pleistocene. Well records show that the thickness of these surface clays and sands ranges from 250 to 350 feet.

[1] P. K. Kelley, "The Sulphur Salt Dome, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), pp. 479-98.

Subsurface.—Sulphur dome is a typical Gulf Coast salt dome composed of a circular, plug-like, central core of rock salt, sedimentary beds dipping quaquaversally away from the salt core, and capped with anhydrite, sulphur, and limestone. The cap rock at 1,100 feet below sea-level has an area of approximately 75 acres, and is almost perfectly circular in plan.

The salt core has a relatively flat top and steep sides. In the center of the field the top of the salt is found at 1,460 feet; on the south flank, in well 743, at 1,770 feet; and on the north flank, in well 729, at 2,593 feet.

The cap rock of this dome is about 1,100 feet thick. It is composed of almost pure limestone, grading into a transition zone of dolomitic lime, calcite, gypsum, and anhydrite. Nine hundred feet of pure anhydrite rests on top of the salt. The sulphur was contained in the transition zone.

Wells drilled on the flanks pass through ledges of rock which are evidently projections from the main mass of the cap. Sands, gumbos, and shales lie between these ledge-like projections.

Most of the beds surrounding the salt core and cap are clay, sand, gravel, gumbo, and sandy shale. Over the top of the dome there are 250 feet of blue, yellow, and red clays alternating with sandy clays, gumbos, and sands. From this depth to the cap is Lafayette gravel. On the west and northwest flanks the gravels extend down to about 1,500 feet, and on the south the wells penetrate gravel and boulders to about 1,700 feet.

The south side of the salt core is much nearer vertical than the northwest side, as shown in the cross section (Fig. 1). In well 741 the cap rock and salt protrude beyond the main salt stock, forming an overhang. Between 1,700 and 2,000 feet this well passed through 60 feet of rock, then 80 feet of salt, and went back into sedimentary beds after going through several thinner ledges of rock. Oil showings were found in sands between the rock ledges. The well was completed as a producer at 3,119 feet. It is evident from the performance of this well that other wells drilled to the salt on steep flanks of the dome should penetrate the salt several hundred feet before being abandoned.

STRATIGRAPHY

The stratigraphic section as determined from lithology and microfossils is as follows.

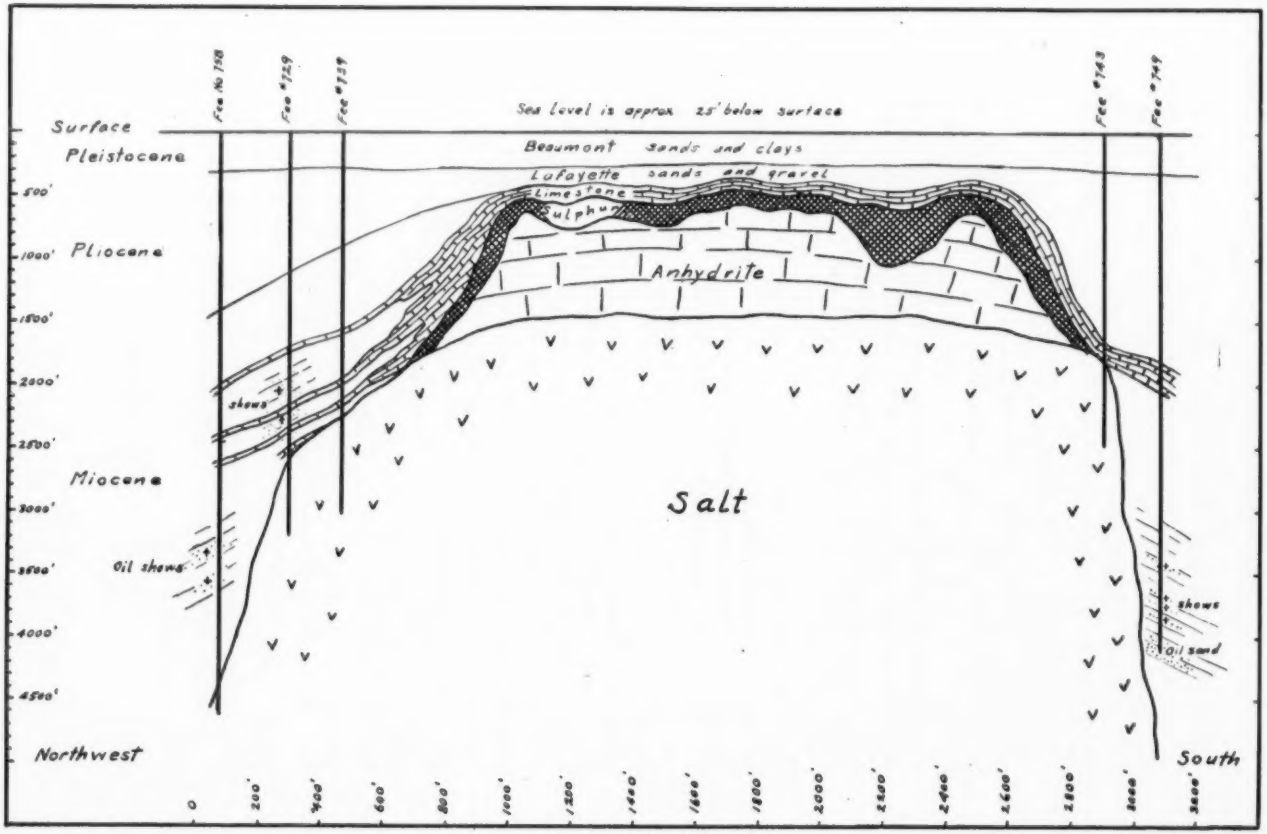

FIG. 1.—Section *A-A*. Scale in feet.

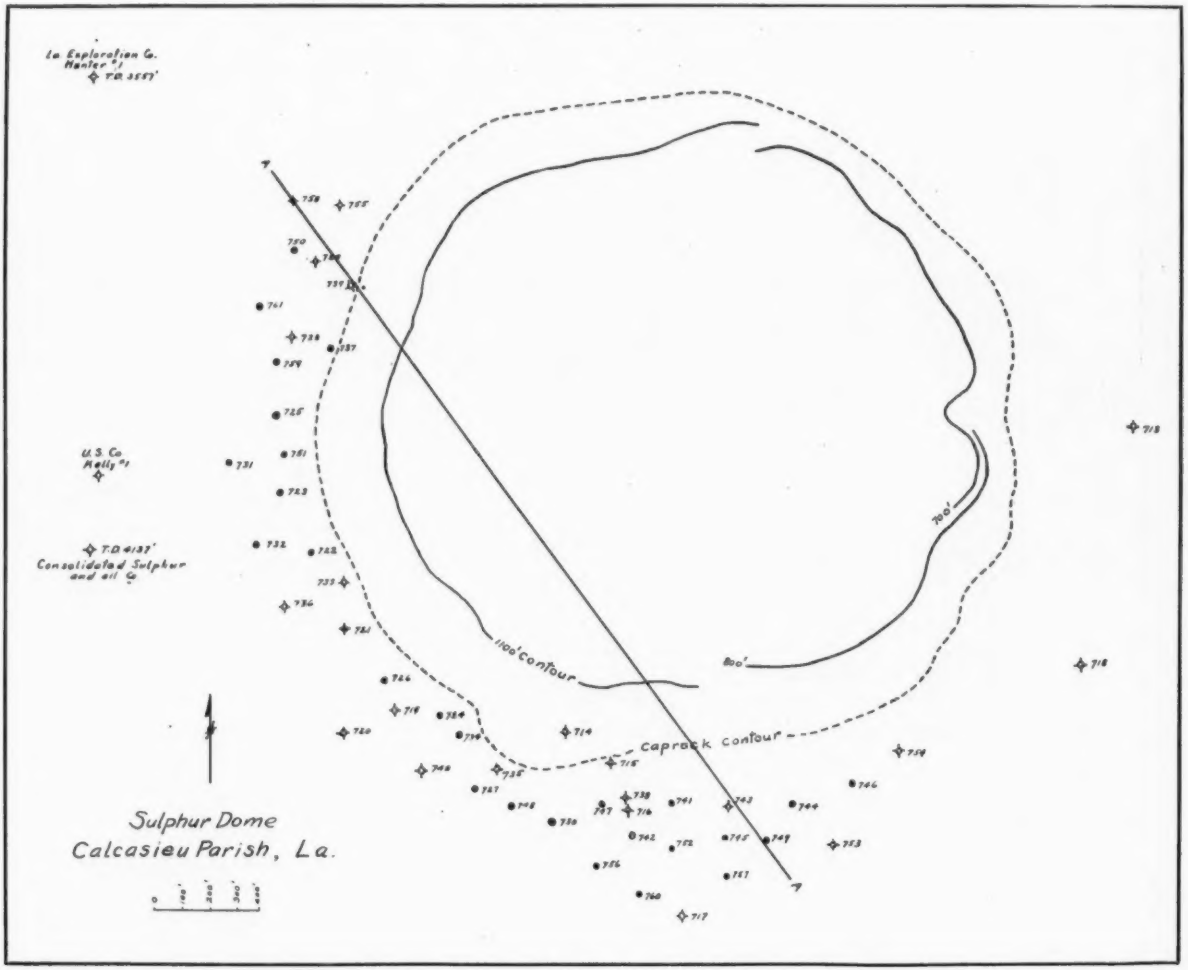
La Exploration Co.
Hunter #1
T.D. 3557'
U.S. Co.
Molly #1
T.D. 4137'
Consolidated Sulphur
and oil Co.
1100' Contour
800'
700'
Caprock contour
Sulphur Dome
Calcasieu Parish, La.

FIG. 2

TABLE I

List of Wells Drilled for Oil on the Sulphur Salt Dome

Well Number	*Flank*	*Date Completed*	*Total Depth in Feet*	*Top of Oil Sand in Feet*	*Initial Production, in Barrels*	*Remarks*
Fee 713	E		4,177	....	....	Abandoned
714	S	7- 8-25	1,452	....	....	Abandoned
715	S	10-22-25	1,583	....	....	Abandoned
716	S	10-19-25	1,840	....	....	Abandoned
717	S	2-17-26	4,120	....	....	Abandoned
718	E	8-12-26	4,581	....	....	Abandoned
719	SW	12-19-26	3,414	....	400	Deepened to 3,619; tested salt water
720	SW	7- 7-27	4,779	....	....	Twisted off—abandoned
721	SW	10- 1-27	3,355	3,327	200	Pumped dry—abandoned
722	W	3-14-28	3,401	3,460	1,300	
723	W	4-19-28	3,297	3,189	1,250	
724	SW	4- 9-28	4,002	3,996	454	
725	W	6- 2-28	3,429	3,358	2,890	Deepened to 4,201, I. P. 374; deepened to 4,526, I. P. 1,127
726	SW	6-18-28	3,235	3,209	3,204	
727	S	6- 2-28	4,045	4,010	1,900	
728	W	9-15-28	6,081	....	....	Abandoned (caving)
Kelley 1	W	9-15-28	5,422	....	....	Abandoned (caving)
Fee 729	NW	8- 1-29	3,201	....	....	Abandoned in salt
730	S	10-30-28	5,700	....	....	Sidetracked to 5,672, I. P. 1,200
731	W	12-16-28	4,849	4,833	1,536	
732	W	9-29-28	3,262	3,244	1,537	
733	W	2-10-29	6,104	....	....	Abandoned
734	SW	11-25-28	4,126	4,085	1,945	
735	SW	2-13-29	6,058	....	....	Abandoned
736	W	8-18-29	6,064	....	....	Abandoned
737	W	1-12-29	3,175	3,152	1,274	
738	S	1- 1-29	2,848	....	....	Blowout destroyed casing; abandoned
739	NW	3- 8-29	3,018	....	....	Abandoned in salt
740	SW	3-19-29	6,260	....	....	Abandoned
741	S	3-24-29	3,119	3,101	1,200	
742	S	4-20-29	2,946	2,924	1,000	Deepened to 5,018, I. P. 2,200
743	S	4- 5-29	2,500	....	....	Abandoned in salt
744	S	5-21-29	3,429	3,370	1,500	
745	S	5-21-29	3,616	3,602	2,300	
746	S	8-29-29	4,159	4,155	1,493	
747	S	7-18-29	2,801	2,770	750	
748	S	7-27-29	4,059	4,036	1,843	
749	S	8-28-29	4,154	4,138	3,038	
750	NW	9-30-29	3,333	3,309	1,100	
751	W	9-24-29	3,356	3,335	2,442	
752	S	10-17-29	3,379	3,346	1,400	Deepened to 4,088, I. P. 2,910
753	S	12- 4-29	4,343	4,314	1,372	
754	SE	1-30-30	5,011	....	....	Abandoned in salt
755	NW	11-26-29	3,280	....	....	Abandoned in salt
756	S	2-19-30	4,773	4,767	2,548	
757	S	4- 4-30	4,103	4,093	3,168	
758	NW	2- 6-30	3,370	3,350	380	Deepened to 4,618; abandoned in salt
759	W	2-26-30	3,425	3,416	1,157	
760	S	7- 5-30	4,867	4,854	2,000	
761	NW	7- 4-30	3,347	3,324	170	

Age	*Formation*	*Lithology*	*Thickness in Feet*
Pleistocene	Beaumont	Clays and sandy clays	250- 350
Late Pliocene	Lafayette	Gravels and sands	1,000-1,700
Pliocene } Miocene }	Fleming	Gumbos, shales, sandy shales, sands, and rock ledges	2,500
Oligocene	Oligocene	Sands, sandy shale, hard shales, and limestone	?

PALEONTOLOGY

A small indigenous fauna is found in the middle Miocene, and nine wells have penetrated the *Heterostegina* zone of the middle Oligocene. The Oligocene carries the characteristic micro-fauna as found in Oligocene beds of other Gulf Coast domes.

OIL AND GAS

Oil.—Attention was first attracted to this area by a small oil seepage and an alum well on the western side of the low ridge which extended into Sulphur Mine marsh. Heavy oil was encountered in some of the sulphur wells drilled on top of the dome. Prospecting for oil on the flanks began in 1925, and to date fifty wells have been drilled which have produced almost 3,000,000 barrels (Table I). These wells cover approximately 30 acres on the south and west flanks of the dome, making an average of 1 ⅔ wells per acre (Fig. 2).

The producing oil "sands" of the Miocene range from 2,750 to 4,750 feet, and well 730 is producing from the middle Oligocene at 5,672 feet. Deep production has hardly been explored; well 730 is the only producer below the Miocene.

The oil has been classified as Grade A with a gravity of 22.4 and Grade B with a gravity of 26.5. There seems to be no relationship between the grade of oil and the depth from which it comes, as Grade A oil comes from above and below the horizon from which Grade B is produced.

Gas.—The daily average production of gas is approximately 500,000 cubic feet. This is run through separators and utilized as fuel for operating the drilling rigs.

FUTURE OF FIELD

The future prospects of this dome seem very good, inasmuch as several wells have already proved the presence of a deep "pay" below

the Miocene, and inasmuch as the north and east flanks have not been explored.

A. J. BAUERNSCHMIDT, JR.[1]

SULPHUR, LOUISIANA
July 10, 1930

[1]Paleontologist, The Union Sulphur Company.

DISCUSSION

MAGNETOMETER STUDY IN LOUISIANA

On page 183 of his article on "Magnetometer Study of the Caddo-Shreveport Uplift, Louisiana," Barret, in the February *Bulletin*, makes the statement,

> Over the geologic section shown, the magnetic profile would bear a striking relation to the gravity gradient in torsion-balance work, which is significant in the light of Albert Einstein's recently established identity.

Although there may be doubt in the minds of some readers, including myself, concerning the accuracy of the first part of this statement, there is no doubt whatever that the reference to Einstein is meaningless. The connection which Barret implies between magnetic and gravitational fields and the discovery which he credits to Einstein does not exist in the form he seems to believe.

Einstein's first work was to show in his restricted theory of relativity that gravitational phenomena could be expressed by a space-time geometry. He later expanded this theory into the general theory of relativity by taking account of shifting and relative coördinate systems.

Later the question arose as to whether electromagnetic phenomena might not be expressed by the same method, namely, a form of space-time geometry. This Einstein was successful in doing. At present it is under considerable fire from the mathematical physicist, however.

There has been no connection whatever found, to my knowledge, between gravitational and magnetic fields and certainly no identity, as Barret expresses it.

On page 178, last paragraph, Barret discusses the effect of casing on magnetic readings in producing areas. He states that in his opinion the effect of the iron weakens the field in the region surrounding the metal. He further states that a judicious selection of stations can minimize the effect of the metal.

The great difficulty in getting a judicious selection of positions lies in the asymmetrical spatial distribution of the field referred to the casing head, of a vertical string of casing, for example. The actual field may be considered to be made up of two parts; one, the undistorted earth's field, and the other, the induced field of the casing. If these two vector fields are added, they will give the actual value of the field at any point. The fields will have essentially opposite directions in the region extending out from the casing near its vertical midpoint. This would correspond with a decrease in field strength. This may be several thousand feet underground. The weakening effect will become less as the surface is approached and the field bends toward the casing. In the area immediately around the casing head the total field will be considerably greater because of the casing.

The calculation of the total field for all points in a horizontal plane through the casing head would show the asymmetry of the spatial distribution, but this unfortunately is complicated by several unknown factors.

Seemingly the only safe location would be far enough away for the field effects of the casing or metal to be negligible.

B. B. WEATHERBY[1]

TULSA, OKLAHOMA
June, 1930

PROSPECTIVE OIL TERRITORY IN TURKEY

Thanks are due to the director of the Bureau of Mines and to Shakir Bey, the Minister of Economy, for permission to discuss the paper by Shirley Mason on the "Geology of Prospective Oil Territory in Republic of Turkey" published in the June *Bulletin* (pages 687-704) of this Association in advance of the scheduled printing of the Ministry's papers on these regions. Mr. Mason deserves praise for what happens to be the first published description of part of the petroleum territory in Turkey seen with the eye of a modern petroleum geologist. Mr. Mason has visited three of the seven or eight provinces with petroleum possibilities in the Turkish Republic. The others are in the vilayets of Antalia, Erzindjan, Erzerum, and Van. Inasmuch as perhaps the most important, that of the Mardin region, has been included, the paper is of decided value.

The Murefte section, in European Turkey, has received the greatest attention by the geologic fraternity, principally on account of its proximity to Constantinople. It lies within 85 miles of the former capital. A well drilled to a depth of 293 feet and 4 inches approximately 40 years ago obtained a small amount of 0.825 gravity paraffine-base oil. The production varied from 1 ton to 3 tons (7 to 21 barrels) and lasted only a few days before the well ceased flowing. Two more wells have been drilled with unknown results. The holes referred to by Mr. Mason as surrounding the ephemerally productive well can not be dignified with the name of test holes. They are all large hand-dug pits, none deeper than 40 feet and none penetrating the surface gravel. There may be important structural considerations vitiating the possible productivity of the region, but the fact that nine test holes were drilled and found dry is not one of them. On the general stratigraphy there is a general accord. The white limestone on the top of Mount Elie (Mount Elie limestone) is considered Eocene. The thick Arably conglomerate at the Arably Canyon is probably basal Oligocene. This, as well as the overlying blue shales, however, has been included in the Eocene by some geologists. There is no good paleontological evidence for either assumption. The lower Miocene shales or the "variegated shales" are not more than 300 feet in thickness and the overlying sandstone group can not exceed 1,000 feet. The *Mactra* limestone, with a profusion of *Mactra* shells and with dips as steep as 15°, is believed to be Pliocene.

The eastern province, or the Mardin area, has received the least attention from the geologists. The difficulties and hardships in reaching it should be more than balanced by its position at the edge of a large basin which at two other parts in two different countries has been the source of prolific production. I agree with the author that the blue limestone—somewhat dark blue shaly lime-

[1]Introduced by Sidney Powers.

stone—is probably Paleozoic. I found near Harbol a bed containing a profusion of *Productus*, corals, and bryozoans. I am surprised, however, to see the dark shales above the greenish sandstones and shales. In the trip from Jezire to Sharnak and Zivengok one could not possibly fail to observe everywhere the dark shales underlying the greenish series. This is of exceeding importance, as it establishes a very favorable relation between the source and the possible reservoir beds. Though erosion has exposed the source and the reservoir beds on several structures, on others, some of which are shown on Mr. Mason's own map, there is several hundred feet of cover. I suspect Mr. Mason did not see the Zivengok area, however. Under "Seepages" I notice reference only to Kerbent and no mention of the much more prolific Zivengok seepage, where two gallons of oil may be collected hourly. The red beds overlying the greenish shales and sandstones are believed to be Eocene, though no fossils were found in them. They underlie the escarpment-forming limestone of Kasyrik and Besbin, east of the Tigris. These limestones are nearly 2,000 feet in thickness and contain many *Oligopygus* sp. They are considered Oligocene and the equivalent of the Asmari. The white limestones of the Nusaybin and Kerboran area must not be confused with the previously mentioned limestone. The limestones of the Midyat-Kerboran-Siirt section are also white, but they overlie the reddish shales with gypsum and Sarmatian (upper Miocene) fossils. They are, therefore, considered Plio-Miocene and are suggested as the equivalent of the thick reddish continental deposits east of the Tigris between the Khabur Su on the Iraq frontier and the mountains on the north. I quite agree with Mr. Mason that the upper part of these reddish continental deposits is the equivalent of the Bakhtiari and the lower part probably corresponds with the upper Fars. The section at Mardin is considerably higher than we have been led to believe. The upper part is certainly Miocene and the lowest exposed part Tertiary. The region has structures of many descriptions ranging from overthrusts to gentle and broad anticlines, as Mr. Mason points out.

However, I distinctly disagree with the concluding remarks. The author concludes that not even small production may be expected. His principal reasons are: (1) the absence of the Asmari limestone and (2) the calcareous and thin condition of the source beds where the structure is favorable. Both statements seem unwarranted. Furthermore, the reservoir horizon in this part of the Mesopotamian basin is probably the sands overlying the black shales where the structure is favorable and the cover sufficient. These optimum conditions are satisfied in several localities of the general region.

DJEVAD EYOUB

ANKARA, TURKEY
June, 1930

REVIEWS AND NEW PUBLICATIONS

RECENT PUBLICATIONS

CALIFORNIA

"Explanation of Elwood Geology," by A. Francis Mercer. *Calif. Oil World* (Los Angeles, June 26, 1930), pp. 9, 10.

COLORADO

U. S. Bur. Mines Bull. 315, by Martin J. Gavin and John S. Desmond. Review of oil shale investigations. (Supt. Documents, Washington, D. C.) Price, $0.70.

CROOKED HOLES

"Crooked Holes," by Paul J. Howard. *California Oil Fields*, Vol. 14, No. 12 (June, 1930), pp. 4-24, 5 figs., 1 map. (Department of Natural Resources, Division of Oil and Gas, San Francisco, California.)

EUROPE

Geologie von Europa, by Serge von Bubnoff. Vol. II, *Das ausseralpine Westeuropa*, Part I, *Kaledoniden und Varisciden*. (Gebrüder Borntraeger, Schöneberger Ufer 12a, Berlin W. 35, Germany.) 691 pp., 4 pls., 201 figs. 52 Mk. 50 Pfg. (approx. $13.00).

GENERAL

"Beiträge zur Geologie der Salzstöcke, Erdfälle und Erdöllagerstätten im Landkreise Celle," Part II, by H. Werner. *Intern. Zeits. für Bohrtechnik, Erdölbergbau und Geologie* (Vienna, June 15, 1930), pp. 121-26, 4 illus. Part I published June 1, 1930, pp. 109-14.

"Bibliography of Seismology," by Ernest A. Hodgson. *Publications of the Dominion Observatory*, Vol. 10, No. 4 (October, November, December, 1929, Ottawa, Canada), pp. 51-65. Price, $0.25.

KENTUCKY

"Pleistocene of Northern Kentucky," by Frank Leverett. One of four articles bound in one volume, including "Geology of the Southern Part of the Dawson Springs Quadrangle," by A. H. Sutton, and "The Cretaceous Deposits of Trigg, Lyon, and Livingston Counties, Kentucky," by J. K. Roberts. *Kentucky Geol. Survey* (Frankfort, 1929), Ser. 6, Vol. 31. 403 pp., 16 photographs, map, and diagrams.

NICARAGUA

"Nicaragua—Its Geology and Oil Possibilities," by William C. Marshall. *Oil Bulletin* (Los Angeles, California, July, 1930), pp. 720-24, 12 illus.

OKLAHOMA

"Study of the Black Shale Overlying the Cap Rock of the Cromwell Sand in Relation to the Origin of the Cromwell Oil Dome, Oklahoma," by Oliver C. Grawe. *Econ. Geol.*, Vol. 25, No. 4 (June-July, 1930), Urbana, Illinois, pp. 326-47, 5 figs.

The Oklahoma Geological Survey, Norman, Oklahoma, announces the following publications.

"Oil and Gas in Oklahoma. Jefferson County," by John R. Bunn. *Bull. 40-PP*. 45 pp., 2 pls., 5 figs. Price, $0.30.

"Oil and Gas in Oklahoma. Cherokee and Adair Counties," by Ira H. Cram. *Bull. 40-QQ* (Norman, May, 1930). 60 pp., 3 pls., 4 figs.

"Oil and Gas in Oklahoma. Tulsa County," by W. F. Cloud. *Bull. 40-RR*. 29 pp., 3 pls., 10 figs., 4 tables. Price, $0.30.

"Oil and Gas in Oklahoma. Oklahoma County," by A. Travis. *Bull. 40-SS* (Norman, May, 1930). 32 pp., 3 pls., 7 figs.

"Oil and Gas in Oklahoma. Pottawatomie County," by T. E. Weirich. *Bull. 40-TT* (Norman, May, 1930). 15 pp., 6 figs.

"Oil and Gas in Oklahoma. Blaine, Dewey, Custer, and Roger Mills Counties," by Ray L. Six. *Bull. 40-UU*. 53 pp., 3 pls., 6 figs. Price, $0.30.

"Oil and Gas in Oklahoma. Lincoln County," by Dollie Radler. *Bull. 40-VV*. 16 pp., 1 pl., 7 figs. Price, $0.30.

"Oil and Gas in Oklahoma. Beaver, Texas, and Cimarron Counties," by Ray L. Six. *Bull. 40-WW*. 35 pp., 5 pls., 4 figs. Price, $0.30.

"Oil and Gas in Oklahoma. Hughes County," by J. Phillip Boyle. *Bull. 40-XX*. 19 pp., 1 pl., 5 figs. Price, $0.30.

TENNESSEE-KENTUCKY

"Revision of the Lower Eocene Wilcox Flora of the Southeastern States, with Descriptions of New Species, Chiefly from Tennessee and Kentucky," by E. W. Berry. *U. S. Geol. Survey Prof. Paper 156* (Supt. Documents, Washington, D. C.). 196 pp., 50 pls., 32 figs. Price, $0.75.

TEXAS

"Magnetometer Results in Lea County," by L. Spraragen. *Oil and Gas Jour.* (Tulsa, Oklahoma, June 26, 1930), pp. 34, 92, 94, 3 illus. Part I published June 12, 1930, pp. 91-92.

"Results of Air Repressuring and Engineering Study of Williams Pool, Putnam-Moran District, Callahan County, Texas." *U. S. Bur. Mines Technical Paper 470* (Supt. Documents, Washington, D. C.). Price, $0.15.

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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AT HOME AND ABROAD

J. J. GALLOWAY, of Columbia University, is spending the summer at Ardmore, Oklahoma, for the Gypsy Oil Company.

C. R. CLARK is in charge of geological work at Seminole, Oklahoma, for the Gypsy Oil Company.

G. C. POTTER, formerly chief geologist of the McMan Oil and Gas Company, has joined the staff of the Dixie Oil Company, at Tulsa, Oklahoma.

WALLACE LEE is now engaged in consulting work at Okmulgee, Oklahoma.

G. S. HUME, of the Canadian Geological Survey, is working in the Calgary area.

GEORGE SHEPPARD, state geologist of the Republic of Ecuador, has an article on "Notes on the Climate and Physiography of Southwestern Ecuador" in the July issue of *Geographical Review*.

H. E. FORGUSON, consulting geologist for the Penn Oil Company, and HAROLD VANCE, consulting geologist for the Balance Oil Company, Ltd., have formed a partnership as consulting geologists and petroleum engineers, with offices at San Antonio and Midland, Texas.

MOSES M. KORNFELD is employed in the Wichita, Kansas, office of the Atlantic Oil Producing Company, in the capacity of subsurface geologist.

WALT M. SMALL, formerly field manager of the Cia. de Petroleo de Angola, Loanda, Angola, West Africa, has returned to the United States. Mr. Small's permanent address is Cooperstown, Pennsylvania.

CHARLES H. BEHRE, JR., has left the geological department of the University of Cincinnati to accept an associate professorship of economic geology at Northwestern University.

CARLTON D. HULIN, of the department of geology, University of California, Berkeley, has an article on "A Mother Lode Gold Ore" in the June-July issue of *Economic Geology*.

ALAN M. BATEMAN, of Yale University, New Haven, Connecticut, has an article on "The Ores of the Northern Rhodesia Copper Belt" in the June-July issue of *Economic Geology*.

RICHARD L. MANNEN, geologist for Catlett and O'Neil at Beeville, Texas, has resigned and accepted a position with the Sinclair Oil and Gas Company, in the same territory.

JOHN R. SUMAN, vice-president of the Humble Oil and Refining Company, Houston, Texas, has been appointed national chairman of the A.P.I. Committee

on Standardization of Oil Company Tubular Goods. He succeeds CHARLES FITZGERALD of the Pure Oil Pipe Line Company, who has been made national vice-chairman.

JOHN FRANKLIN DODGE, chairman, division of petroleum engineering, University of Southern California, has an article on "Educating Engineers for the Petroleum Industry" in the July 1 issue of *Oil Field Engineering*.

C. A. HEILAND, professor of geophysics at the Colorado School of Mines, Golden, sailed for Germany in June. He will return to Golden about the first of September.

JAMES S. WILLIAMS, of the department of geology at the University of Missouri, Columbia, has an article on "A Color Pattern on a New Mississippian Trilobite" in the July issue of the *American Journal of Science*.

ROBERT B. CAMPBELL moved in June from San Angelo to San Antonio, Texas, where he will engage in consulting work, with offices at 2119 Alamo National Building. Mr. Campbell was recently re-elected to serve his second term as president of the National Association of Consulting Geologists.

ALFRED R. EYSSELL is vice-president of the Peerless Oil and Gas Company. His address is 813 Alamo National Building, San Antonio, Texas.

HARRY P. STOLZ is chief petroleum engineer for the Sunset Pacific Oil Company, Pacific Electric Building, Los Angeles, California.

STANLEY M. WALKER has moved from Henderson, Kentucky, to Denver, Colorado, where he will resume his consulting practice. He will, however, still continue drilling operations in Kentucky. His address in Denver is 1320 Humboldt Street.

DAVID P. DEAN is now representing the Barnsdall Oil Company at Jackson, Mississippi.

E. W. KRAMPERT, geologist for the Prairie Oil and Gas Company at Parco, Wyoming, has returned to Wyoming, after having offices for several months at Meridian, Mississippi.

A general committee on stratigraphic nomenclature of formations crossing state boundaries has been appointed by several geological organizations as the outgrowth of a proposal by the American Association of State Geologists in Washington, D. C., last year. The representatives of the state geologists are: R. C. MOORE, of Kansas, G. H. ASHLEY, of Pennsylvania, and CHARLES N. GOULD, of Oklahoma; the representatives of the U. S. Geological Survey: T. W. STANTON, H. D. MISER, and G. W. STOSE, of Washington, D. C.; of The American Association of Petroleum Geologists: A. I. LEVORSEN, of Oklahoma, M. G. CHENEY, of Texas, and C. J. HARES, of California; of the Geological Society of America: J. J. GALLOWAY, of New York, W. H. TWENHOFEL, of Wisconsin, and B. F. HOWELL, of New Jersey. The meeting held at Urbana, Illinois, last April, of which CHARLES N. GOULD was chairman and R. C. MOORE was secretary, voted to hold the next meeting at Toronto, Canada, on the day following the meeting of the Geological Society of America next winter.

JOSIAH BRIDGE has resigned from the faculty of the Missouri School of Mines, Rolla, to accept an appointment as paleontologist for the U. S. Geological Survey to assist E. O. ULRICH.

D. E. BREMER, geologist for The Texas Company, is stationed at Jackson, Mississippi.

C. M. DORCHESTER, of the Gulf Refining Company, is living at Jackson, Mississippi.

I. K. HOWETH, consulting geologist of Beeville, Texas, located the new gas well of the Lion Oil Refining Company on the MacFadden ranch, Victoria County, Texas.

VIRGIL O. WOOD, consulting geologist, of Tulsa, Oklahoma, is spending the summer in California.

EVERETT CARPENTER has moved from Bartlesville, Oklahoma, to Amarillo, Texas, where he is representing the Texas-Interstate Pipe Line Company, 612 Oliver Eakle Building.

L. W. HEWITT, of San Antonio, Texas, has resigned from the Continental Oil Company.

ARTHUR IDDINGS, who is manager of the producing properties of the London-Pacific (International Petroleum Corporation) at Negritos, Talaria, Peru, spent his vacation in the United States.

W. D. MATTHEW, of the University of California, has been working on the Tertiary vertebrate fauna of the Texas Panhandle.

C. L. DAKE, of the Missouri School of Mines, Rolla, Missouri, will do consulting work in West Texas this fall.

A. F. MELCHER, of Tulsa, is spending the summer at Bradford, Pennsylvania.

W. Z. MILLER, of Tulsa, is working in the Rocky Mountain states.

J. M. LOVEIOY, of New York City, is spending the summer in California.

A. A. LANGWORTHY, of Tulsa, division geologist of The Pure Oil Company, is spending the summer in the Rocky Mountains.

ROBERT C. LAFFERTY has accepted a position with the Columbian Carbon Company of Charleston, West Virginia, for geological work in the district including West Virginia and eastern Kentucky and Tennessee.

J. W. BEEDE, of the department of geology of Indiana University, is in southern New Mexico, where he expects to spend several months studying the Permian in that region.

On June 13, 14, and 15, the eighteenth field conference under the direction of the Oklahoma Geological Survey was held in the Arbuckle Mountains. There

were 91 geologists in attendance. CHARLES E. DECKER, assisted by REX MCGEHEE, led the party, the object of which was to study the outcrop of the Simpson on the periphery of the Arbuckles.

On June 20, 21, and 22, a field conference under the direction of CHARLES N. GOULD, director of the Oklahoma Geological Survey, was held in the Wichita Mountains. There were 48 geologists in attendance. This party was organized by the Panhandle Geological Society, of Amarillo, the object being to study exposures in the Wichitas of rocks encountered by deep drilling in the Panhandle of Texas. CLYDE BECKER and J. F. HOWELL were leaders.

During the present summer the Oklahoma Geological Survey has the following parties in the field. In the Arbuckle Mountains CHARLES E. DECKER is continuing his work on the Simpson, assisted by REX MCGEHEE. Other field assistants are ROSS MAXWELL, J. E. ORR, and W. S. BEARDSLEY. SAMUEL WEIDMAN, assisted by EDWIN S. SMITH, JR., is continuing work in the lead and zinc fields of northeast Oklahoma. Work on the coal fields of eastern Oklahoma begun several years ago by W. T. THOM, JR., of the U. S. Geological Survey, is being continued in Muskogee County by C. W. WILSON, assisted by THOMAS L. METCALF. G. WILLIS STOVALL, of the University of Oklahoma, is collecting Permian vertebrates in the Red-beds of western Oklahoma. JOHN S. REDFIELD, of the Oklahoma Geological Survey, is continuing the collection of clays of Oklahoma, and these clays are being tested in the ceramics laboratory of the A. and M. College at Stillwater under the direction of Professor LEONARD SHEERAR.

JOHN F. WEINZIERL, consulting geologist and geophysicist, Houston, Texas, was married Monday, June 16, at Christ Church, Houston, to Miss MARY C. MARRS, daughter of Mr. and Mrs. S. M. N. MARRS, of Austin.

SCOTT TURNER was appointed, by the Secretary of State, as a delegate on the part of the United States to the second plenary meeting of the World Power Conference held at Berlin the latter part of June. He was also appointed one of the two American delegates on the part of the United States to the International Congress of Mining, Metallurgy and Applied Geology, held at Liège, the end of June.

WILLIAM C. MARSHALL, geologist for the California-Mammoth Oil Company, has returned to Los Angeles, after an extended tour of Nicaraugua.

JACK T. PERKINS, geological scout for the Amerada Petroleum Corporation in New Mexico, was married June 1 at Carlsbad to Miss GLADYS CHOATE, of Carlsbad. Their home will be in Lovington.

C. A. MCADAMS, formerly district geologist for the White Eagle Oil and Refining Company (now White Eagle Oil Corporation), and HORACE ROYER, formerly district land man for the same company, have formed a partnership, with offices in the Fourth National Bank Building, Wichita, Kansas.

EMIL KLUTH, petroleum engineer for George F. Getty, Inc., Los Angeles, is making an extended European tour in order to study European development. He is accompanied by his wife and daughter.

C. A. HEILAND, of the Colorado School of Mines, Golden, Colorado, is the author of the A. I. M. M. E. Technical Publication 330, entitled" A New Geophone."

SIDNEY A. PACKARD, recently chief geologist for the Louisiana Oil Refining Corporation, has accepted a position in the Shreveport office of the Arkansas Natural Gas Corporation.

STUART MOSSOM has resigned from the Ohio Oil Company, Shreveport, Louisiana, to become geologist for the Lion Oil Refining Company in the San Antonio division.

The San Antonio Section of the Association recently had the following programs: at the regular monthly meeting on June 2, A. R. DENISON, district geologist for the Amerada Petroleum Corporation at Fort Worth, lectured on "Some Geological Features of Our National Parks;" at the regular weekly luncheon on June 30, F. H. LAHEE, chief geologist for the Sun Oil Company at Dallas, discussed the new constitution and several other current problems of the Association; and at the monthly meeting on July 7, M. G. CHENEY, president of the Anzac Oil Corporation, of Coleman and Fort Worth, talked on "Structural Problems of Central Texas."

RAYMOND A. MOORE is geologist for the Love Petroleum Company, at Jackson, Mississippi.

K. M. WILLSON has resigned from the Douglas Oil Company of Tulsa.

RALPH E. GRIM, assistant state geologist of Mississippi, has resigned.

S. S. PARKER is geologist for the Getty Oil Company at Hobbs, New Mexico.

S. S. PRICE, of Tulsa, is spending the summer in Europe.

GEORGE L. ELLIS is geologist for the Universal Gas and Fuel Company, of Columbus, Ohio.

R. C. LAMB has been transferred from the Wichita Falls district of the Barnsdall Oil Company to the Amarillo district. His address is now 220 Rule Building, Amarillo, Texas.

W. E. WRATHER, Dallas, Texas, and W. A. J. M. VAN DER GRACHT, Feldbach, Steiermark, Austria, have been studying the geology of the Alps.

F. B. PLUMMER has been appointed professor of petroleum production engineering at the University of Texas, Austin, effective September 15.

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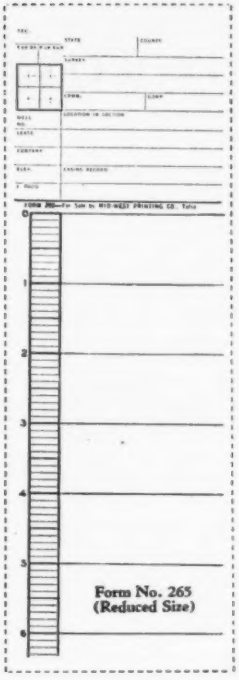

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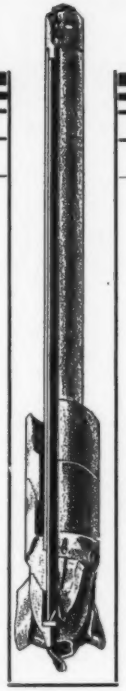

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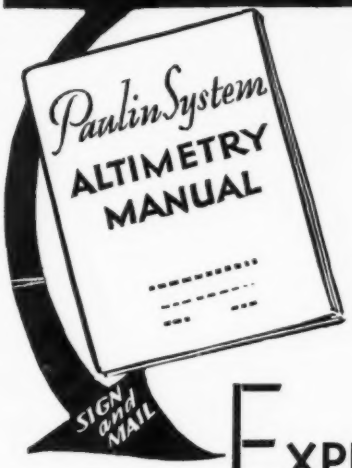

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